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Remedial Action Contract

Final Feasibility Study Report

Maunabo Groundwater Contamination Site

Remedial Investigation/Feasibility Study

Maunabo, Puerto Rico

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CDM Smith

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Acronyms and Abbreviations

amsl	above mean sea level
APE	area of potential effects
ARAR	applicable or relevant and appropriate requirement
AS/SVE	air sparging/ soil vapor extraction
bgs	below ground surface
°C	degrees Celsius
CAA	Clean Air Act
CAH	chlorinated aliphatic hydrocarbons
CAM	Centro de Acopio Manufacturing
CDM Smith	CDM Federal Programs Corporation
CERCLA	Comprehensive Environment Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-dichloroethene
COC	contaminant of concern
CSM	conceptual site model
CWA	Clean Water Act
1,1-DCE	1,1-dichloroethene
DHC	*dehalococcoides* species
DOT	Department of Transportation
EO	Executive Order
EPA	United States Environmental Protection Agency
ERH	electrical resistivity heating
ESD	Explanation of Significant Difference
EVO	emulsified vegetable oil
EZVI	emulsified zero-valent iron
°F	degrees Fahrenheit
foot/day	foot per day
feet/day	feet per day
ft^3/sec	cubic feet per second
FS	feasibility study
FSM	Former Sugar Mill
GAC	granular activated carbon
gpm	gallon per minute
GRA	general response action
HHRA	human health risk assessment
HRS	hazard ranking system
IC	indicator contaminant
ISCO	in-situ chemical oxidation
JUA	Juan Orozco Limited, Inc.
K_{OC}	organic carbon partition coefficient
kg	kilogram
MCL	maximum contaminant level
MEE	methane/ethane/ethene
µg/L	microgram per liter
MNA	monitored natural attenuation
MTBE	methyl tert-butyl ether

NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PCE	tetrachloroethene
PHP	Plastic Home Products
POTW	publicly owned treatment works
PPE	personal protective equipment
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRB	Puerto Rico Beverage
PRDNER	Puerto Rico Department of Natural and Environmental Resources
PRDOH	Puerto Rico Department of Health
PREQB	Puerto Rico Environmental Quality Board
PRG	Preliminary Remediation Goal
PRIDCO	Puerto Rico Industrial Development Corporation
PRWQS	Puerto Rico Water Quality Standards
RAC	Remedial Action Contract
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
redox	reduction-oxidation
RGA	Richard Grubb & Associates, Inc.
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
SAT	Site Assessment Team
SF	FEMA Storage Facility
SLERA	screening level ecological risk assessment
Site	Maunabo Groundwater Contamination Site
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TBC	to be considered
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
T/M/V	toxicity, mobility, or volume
TOC	total organic carbon
USFWS	United States Fish and Wildlife Service
UIC	underground injection control
UV	ultraviolet
VOC	volatile organic compound
VC	vinyl chloride
ZVI	zero valent iron

Section 1

Introduction

CDM Federal Programs Corporation (CDM Smith) received Work Assignment 171-RICO-02XF under the Response Action Contract. The project was subsequently transferred to the Remedial Action Contract (RAC) as Work Assignment 014-RICO-02XF. CDM Smith was tasked to perform a Remedial Investigation/Feasibility Study (RI/FS) for the United States Environmental Protection Agency (EPA) Region 2 at the Maunabo Groundwater Contamination Site (the Maunabo Site or the Site) located in Maunabo, Puerto Rico.

This Feasibility Study (FS) was prepared in accordance with the CDM Smith Final Work Plan Volume I (CDM Smith 2008).

1.1 Purpose and Organization of the Report

The purpose of the FS is to identify, develop, screen, and evaluate a range of remedial alternatives for the contaminated media and to provide the regulatory agencies with data sufficient to select a feasible and cost-effective remedial alternative that protects public health and the environment from potential risks at the Site.

This FS Report was prepared in accordance with Guidance for Conducting Remedial Investigations and Feasibility Studies under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (EPA 1988). This FS Report is comprised of five sections as described below.

- **Section 1 - Introduction** provides a summary of Site background information including the Site description, Site history, physical characteristics of the Site, screening level ecological risk assessment (SLERA), remedial investigation (RI) sampling activities, nature and extent of contamination, contaminant fate and transport, and Conceptual Site Model (CSM). The Human Health Risk Assessment (HHRA) has not been finalized as of the writing of this FS.

- **Section 2 - Development of Remedial Action Objectives and Screening of Technologies** develops a list of remedial action objectives (RAOs) by considering the characterization of contaminants, the risk assessments, and compliance with Site-specific applicable or relevant and appropriate requirements (ARARs); documents the quantity of contaminated media; identifies preliminary remediation goals (PRGs) and general response actions (GRAs) that could potentially achieve the PRGs; and identifies and screens remedial technologies and process options.

- **Section 3 - Development of Remedial Action Alternatives** presents the remedial alternatives developed by combining the feasible technologies and process options.

- **Section 4 - Detailed Analysis of Remedial Action Alternatives** provides preliminary design assumptions regarding the alternatives that were retained. This section also provides a detailed analysis of each alternative with respect to the following seven criteria: overall protection of human health and the environment; compliance with the ARARs; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume (T/M/V) through treatment; short-term effectiveness; implementability; and cost. The two additional criteria: commonwealth acceptance and community acceptance are not evaluated in this FS. An overall comparative analysis conducted to compare and contrast the remedial alternatives is presented.

- **Section 5** - **References** provides a list of references used to prepare the FS Report.

1.2 Site Location and Description

The Maunabo Groundwater Contamination Site is located within an isolated alluvial river valley in the municipality of Maunabo, in the southeastern coastal area of Puerto Rico (Figure 1-1). The Site is surrounded by mountains to the north, east, and west and the Caribbean Sea to the south/southeast. The Maunabo River and several intermittent streams are located in the Site vicinity and flow to the southeast toward the Caribbean Sea. The regional direction of groundwater flow in the Maunabo basin is also toward the Caribbean Sea.

The topography in the Site vicinity slopes south/southwest from the nearby hills, at approximately 180 feet above mean sea level (amsl), toward the Maunabo River at 30 feet amsl. The elevation of the Site area is approximately 40 feet amsl. The Pandura Sierra Mountain Range is located to the north and northeast of the Maunabo region. The Pandura and El Sombrerito hills, at the border with Yabucoa, are the highest elevations in the range. With the exception of the elevations noted above, the rest of the Maunabo area is quite level. As a result, it is geographically considered part of the Southern Coastal Valley.

The Site consists of three distinct groundwater plumes with no identified source(s) of contamination. The Maunabo Urbano public water system consists of four supply wells. Site related contamination has been detected in two of the wells, Maunabo supply wells #1 and #4, serving a population of approximately 14,000 people and managed by the Puerto Rico Aqueduct and Sewer Authority (PRASA). The supply wells range in depth from 80 to 125 feet below ground surface (bgs) in the Maunabo alluvial valley aquifer. The aquifer generally consists of poorly sorted sand, silt, clay, and gravel alluvium, including lenticular deposits of sand, gravel, and cobbles.

1.3 Site History

The Maunabo #1 public supply well was installed in 1961, used until 1974 (Adolphson et al. 1977), and then placed back into service in 2001. Chlorinated volatile organic compounds (VOCs) tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (cis-1,2 -DCE) were detected in Maunabo #1 in March 2002 (16.4 microgram per liter [µg/L], 1.6 µg/L, and 4.3 µg/L, respectively). Only PCE exceeded the Federal Maximum Contaminant Level (MCL) of 5 µg/L. Another VOC, 1,1-dichloroethene (1,1 -DCE) was detected intermittently in subsequent years in both Maunabo #1 and Maunabo #4 at levels beneath the MCL. These VOCs were not present in samples collected from the Maunabo supply wells #2 and # 3 over the same time period. Tap water samples of the distributed water show that the contaminants detected in Maunabo #1 were present in the drinking water system at various times.

In March 2002, Puerto Rico Department of Health (PRDOH) ordered PRASA to close Maunabo #1 due to elevated PCE concentrations above the Federal MCL of 5 µg/L. However, rather than close the well, PRASA opted to treat the groundwater at the wellhead using activated carbon filtration tanks. Post-treatment samples have indicated that PRASA's treatment was not always effective and that contaminated drinking water was reaching the consumers. During an inspection in August 2004, PRDOH observed that the activated carbon treatment tanks at Maunabo #1 lacked the necessary filter medium.

EPA completed a Hazard Ranking System Documentation Package (HRS) in 2006. The Site was listed on the National Priorities List (NPL) on September 27, 2006.

1.4 Previous Site Investigations

In October 2005, EPA's Site Assessment Team (SAT) 2 conducted a Site Investigation that included the collection of water samples from Maunabo supply wells #1, #2, #3, and #4, and also in the distribution water line. Sample results indicated the presence of PCE, cis-1,2-DCE, and, methyl tert-butyl ether (MTBE), a gasoline additive, in Maunabo #1, 1,1-DCE in Maunabo #4, and in post-treatment samples along the distribution line at levels below the MCLs.

In December 2005, SAT 2 conducted a limited investigation of possible sources of groundwater contamination in the Maunabo area. Facilities that were investigated include the former Maunabo Municipal Solid Waste Landfill, PRASA's Wastewater Treatment Plant located close to Maunabo Well #1, El Negro Auto Body/Parts Shop, Total Gas Station, Esso Gas Station, and five light industrial facilities operating under the auspices of the Puerto Rico Industrial Development Corporation (PRIDCO). The five PRIDCO industrial facilities included the following:

- Centro de Acopio Manufacturing (CAM)
- Juan Orozco Limited, Inc. (JUA)
- Puerto Rico Beverage (PRB)
- FEMA Storage Facility (SF)
- Plastic Home Products (PHP)

Based on the October and December 2005 data, SAT 2 concluded that there was insufficient information to determine the source of contamination of the public supply wells.

1.5 Summary of the Remedial Investigation

Field investigation activities for the Maunabo Site RI were conducted from August 2010 through July 2011 (CDM Smith 2012 a). Field investigation activities included the following:

- Groundwater Investigation
  - Groundwater screening survey including lithologic characterization
  - Monitoring well drilling, installation, and development

- Two rounds of groundwater well sampling, Round 1 (March 2011) and Round 2 (June 2011)
- Synoptic water level monitoring
- Natural gamma logging of monitoring wells
- Slug testing of selected monitoring wells
- Long term groundwater elevation monitoring
- Groundwater/surface water interaction study

- Soil Investigation - Collection of surface and subsurface soil samples from two potential source areas
- Surface Water and Sediment Investigation - Collection of surface water, sediment, and porewater samples from Rio Maunabo
- Ecological characterization of the Site and surrounding area
- Cultural resources survey
- Surveying of sampling locations
- Characterization and disposal of investigation-derived waste

1.6 Physical Characteristics of the Study Area

Topography

The Maunabo Site is located in southeastern Puerto Rico, within an isolated alluvial river valley. The Site is surrounded by mountains to the north, east, and west and the Caribbean Sea to the southeast. The highest point in the area is Cerro La Pandura at 1,700 feet amsl and the lowest point is the Caribbean Sea to the southeast. The Rio Maunabo and several intermittent streams are located in the Site vicinity and flow southeast toward the Caribbean Sea.

The topography in the Site vicinity slopes south to southwest from the nearby hills, approximately 180 feet amsl, toward the Rio Maunabo at 30 feet amsl (Figure 1-1). The elevation of the Site area is approximately 40 feet amsl.

Surface Water and Drainage

The Maunabo Site lies between the Quebrada Arenas to the east and the Rio Maunabo to the southwest. Most of the drainage across the Site vicinity flows southwest toward the Rio Maunabo and then discharges to the Caribbean Sea. The estimated average discharge of the Rio Maunabo near the Site is 25 cubic feet per second (ft^3/s). Flow is variable throughout the year, with the lowest flow occurring during the dry winter and spring months. Groundwater discharge forms the baseflow for the river, which receives nearly 50 percent of its annual flow from the alluvial aquifer; although RI data indicates that the river can be a losing stream at certain times of the year, such as the dry season. Groundwater also discharges to some of the smaller tributaries and streams (quebradas) such as Quebradas Arenas, Talante, de los Chinos, and Tumbada. These quebradas generally stop flowing during the dry season. The cessation of flow in the quebradas during dry periods is consistent with the seasonal fluctuation in the water table observed during the RI.

Soil Characteristics

Soil types in the area include (in order of predominance): Talante soils, Vivi loam, Maunabo clay, Coloso silty clay, and Pandura loam. These soil types account for approximately 79 percent of the soils in the study area.

Regional and Local Geology

The Maunabo Site is located within an alluvial valley surrounded by hills composed of igneous plutonic rocks. The units expected to be beneath and adjacent to the Site are described below.

- Unconsolidated Deposits – Quaternary Alluvium Deposits
  The Quaternary alluvium deposits consist of unconsolidated silt, clay, sand, and gravel and underlie the Rio Maunabo valley. The lithology varies widely with numerous discontinuous lenses of clay, silt, and sand. The thickest and most permeable deposits are located within the center of the alluvial valleys and can be up to 200 feet thick (Adolphson et al 1977).

  Lithology noted during RI field activities indicate that soils in the alluvial valley generally consisted of fill overlying interbedded silty sand and clay, with some layers of coarser sand and gravel.

- Bedrock

  The bedrock underlying the unconsolidated alluvial valley is Cretaceous-age igneous plutonic rocks that are mapped as the San Lorenzo Batholith. The San Lorenzo Batholtih is a large expanse of granitic rock that covers an area of 200 square miles and includes three major units: diorite and gabbro, the San Lorenzo granodiorite and tonalite, and the Punta Guayenes plutonic complex. An unnamed fault bisects the Rio Maunabo valley; it strikes northwest to southeast with jointing perpendicular to the fault. In the northwest, the fault runs parallel to the Rio Maunabo.

  Investigation of the bedrock was not part of the RI. However, the top of bedrock was noted in the Maunabo supply well logs and during the field investigation at the terminal depths of groundwater screening and monitoring well borings. Depths to bedrock in borings ranged from approximately 15 feet bgs in the northern portion of the Site area, to 95 feet bgs northwest of Maunabo #4. At MW-N, bedrock was observed at approximately 88 feet bgs, and at MW-O, weathered granodiorite fragments were observed at 63 feet bgs. Bedrock appears to be sloping towards the Rio Maunabo.

Regional and Local Hydrogeology

Groundwater occurs mostly in the unconfined alluvial aquifer of the Rio Maunabo valley, whereas the underlying igneous bedrock yields generally small to moderate quantities of water. Therefore, the alluvial aquifer is the aquifer of concern in the Maunabo area. The average transmissivity obtained from literature values for the alluvial aquifer is 4,000 feet squared per day and the specific capacity is 20 gallon per minute (gpm) per foot of drawdown. Estimated hydraulic conductivities obtained from literature values are estimated to be less than 1 foot per day (foot/day) in the bedrock aquifer and 10 to 100 feet per day (feet/day) in the alluvial aquifer. On a regional scale (Maunabo Valley), groundwater flows toward the southeast, to the Caribbean Sea.

The key features of the Site-specific hydrogeology are summarized below.

- The aquifer of concern in the Maunabo area is the alluvial aquifer of the Rio Maunabo Valley. In general, horizontal groundwater flow is toward the Rio Maunabo, on both sides of the river.

- Synoptic water levels from Round 2, collected during the wet season, show an overall higher potentiometric surface, but the general groundwater flow direction remains toward Rio Maunabo, on both sides of the river.

- Locally, the effects of pumping of Maunabo #1 and Maunabo #4 create regular, daily fluctuations in groundwater levels ranging from 0.1 foot to 2.5 feet. Drawdown decreases exponentially with increasing distance from the pumping well. Precipitation disrupts the drawdown pattern. Recharge rates are moderate and can extend for 5 to 7 days following heavy rain.

- Groundwater in the PRB area flows southwest toward the river. Groundwater flowing northeast from the former sugar mill (FSM) area typically flows under Rio Maunabo toward Maunabo #1. During wet periods, when the water table is higher, shallow groundwater in the FSM area flowing northeast discharges to the river. Deeper groundwater continues to flow under the river toward Maunabo #1, due to the depth of its screen zone. Furthermore, the bedrock around Maunabo #1 slopes in toward the supply well, possibly causing the groundwater to funnel in toward Maunabo #1.

- In the vicinity of supply well Maunabo #4, groundwater flow is southeast toward Maunabo #4 with a southern component toward the Rio Maunabo. Flow is influenced by bedrock, which appears to be sloping toward Rio Maunabo.

- Groundwater flow velocity in the alluvial valley aquifer is moderate, ranging from 0.06 to 0.61 foot/day with an average of 0.40 foot/day.

- Groundwater discharge to the Rio Maunabo is affected by seasonal fluctuations in the elevation of the water table. During the wet season, groundwater levels are higher and groundwater discharges to the river. In the dry season, the water table is lower and the Rio Maunabo is a losing stream. Pumping effects from Maunabo #1 are overlaid on the seasonal pattern, lowering groundwater levels locally during both dry and wet periods.

Climate

The climate for Maunabo, located in southeastern Puerto Rico, is classified as tropical humid and is moderated by the nearly constant trade winds that originate in the northeast. The annual average temperature is 80.9 degrees Fahrenheit (°F). The average annual maximum and minimum temperature for the Maunabo area is 89.5 °F and 72.3 °F, respectively. The lowest temperatures occur in January and February and the warmest temperatures occur in September and October. Monthly average temperatures for January and July are 77.6 °F and 82.2 °F, respectively. Precipitation data from 1981 to 2010 recorded at the Maunabo 66050 rainfall station shows a mean annual precipitation of 72.2 inches. The dry season occurs from January to April where the monthly precipitation average ranges from 2.7 inches to 4.25 inches. The wet season is from May to December where the monthly precipitation average ranges from 5.6 inches to 9.1 inches. Precipitation is a source of freshwater for the Rio Maunabo as well as groundwater in the region. Precipitation data was obtained from the Caribbean Atmospheric Research Center website: http://www.atmos.washington.edu/marka/normals/pr.normals.2010.html

Climate data discussed in this section was reported from the Southeast Regional Climate Center website: http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?pr6050

Population and Land Use

The Maunabo Site is located within the Maunabo Municipality in southeastern Puerto Rico. The Municipality of Maunabo is comprised of 21 square miles with a population of 12,225 and a population density of 582.1 people per square mile. The primary land use in the vicinity is agricultural with some residential, commercial, and light industrial development. The area northeast of Maunabo #1 is primarily residential, with dense residential development along narrow streets. The PRASA wells serve approximately 14,000 people. However, since the population decreased from 12,741 people in the 2000 census to 12,225 people in the 2010 census, the actual number of people served by the PRASA wells may be slightly lower.

1.7 Ecology

An ecological reconnaissance was performed on November 4, 2009 to identify ecological resources in the Site area to support preparation of a SLERA. The ecological reconnaissance focused on undeveloped portions of the study area, more specifically, aquatic and riparian habitats of the Rio Maunabo and Quebrada Arenas since these areas are where ecological receptors would be most prone to exposure from contaminants present in groundwater discharge. However, during the ecological reconnaissance no groundwater seeps were noted.

- Rio Maunabo Area - The river substrate consists primarily of medium to coarse sand. Water depth is limited to a few inches; river width ranges from approximately 15 to 25 feet. The sandy substrate, wide channel, and shallow water create conditions favorable for the formation of exposed sand flats, however no aquatic vegetation was observed during the field event. River banks are steep and heavily vegetated. Where intact, riparian vegetation consists primarily of two distinct communities; herbaceous growth intermixed sporadically with trees, shrubby species, and dense monotypic stands of bamboo. Transition from riparian to upland vegetative communities, in general, is lacking as in most instances riparian habitats abruptly end at the top of the river banks where they are bounded by agricultural or residential properties. Little wildlife was encountered within the area. Small crabs and fish were observed sporadically in the river and a few birds were observed including a gray kingbird, an unidentified wading bird, a species of hawk, and egret.

- Quebradas Arenas Area - The Quebradas Arenas is a small stream no more than three feet wide and several inches in depth. Stream substrate consists mostly of coarse/medium sand intermixed with gravel. Portions of the stream have been channelized with some instances of engineered banks consisting of riprap or other material. In general, vegetative communities and available habitats are representative of disturbed conditions. Riparian vegetation is primarily herbaceous; however, some shrubby species such were observed. Dense stands of kudzo were observed throughout the area. Other species included Mexican primrose-willow, minnieroot, and arrowhead vine. Papaya and banana/plantain fields are also nearby. No wildlife was observed.

EPA reported that a review of United States Fish and Wildlife Service (USFWS) records indicate that five federally-listed species can be found within the municipality of Maunabo. These species include four coastal species, the green sea turtle (*Chelonia mydas),* leatherback sea turtle (*Dermochelys coriacea*), hawksbill sea turtle (*Eretmochelys imbricate*), and the West Indian manatee (*Trichechus manatus manatus*). Since the Site is located more than 0.5 miles from the coast no impacts to these species are anticipated. The fifth species is Guajon or Puerto Rican Demon (*Eleutherodactylus cooki*). Review of critical habitats maps in relation to the project area indicated that this species is not in close proximity to the Site.

The Puerto Rico Department of Natural and Environmental Resources (PRDNER) reported that a review of their records for the Site and surrounding area indicated no known occurrences of listed rare, threatened, and/or endangered species.

1.8 Nature and Extent of Contamination

The nature and extent of contamination was assessed by comparing analytical results for groundwater, soil, sediment, surface water, and seep samples to Site-specific screening criteria. Figures 1-2 through 1-10 display the data used to evaluate nature and extent. Generally, the Site-specific screening criteria are the most stringent value of the following: Federal MCLs, human health or ecological criteria, or groundwater protection criteria. Six chemicals, listed below, were identified as Site-related contaminants in order to focus the discussion of contamination. These chemicals were chosen based on the frequency and magnitude of screening criteria exceedances and previous detections in the PRASA supply wells:

- PCE
- TCE
- cis-1,2-DCE
- 1,1-DCE
- Vinyl chloride (VC)

Groundwater Screening Results

Groundwater screening samples were collected from 35 borings to identify potential source areas, to determine the horizontal and vertical characteristics of groundwater contamination, and to determine locations and depths of RI monitoring wells. Site-related contaminants exceeded screening criteria in groundwater screening samples at the PRB, FSM, and Maunabo #4 areas, as described below and presented in Figure 1-9.

cis-1,2-DCE Plume

This plume is between the PRB facility and the Maunabo #1 supply well. The majority of Site-related contaminant exceedances were located in a boring adjacent to PRB (T1-C). Site-related contaminants were detected from the top of the water table (6 feet bgs) to the deepest sample (66 feet bgs); the highest concentrations were between 16 and 40 feet bgs: 200 µg/L of cis-1,2-DCE and 0.9 µg/L of VC were detected between 36 and 40 feet bgs. Cis-1,2-DCE and VC also exceeded screening criteria downgradient of T1-C, at similar depths. No Site-related contaminants were detected in upgradient screening locations.

PCE Plume

This plume is located between the FSM and Maunabo #1 supply well. Site-related contamination in this area was limited to TCE and PCE, which were detected at four locations (T4-D, T4-B, T4-C, and GS-G), although only PCE (7.4 µg/L at T4-B) exceeded its screening criterion of 5 µg/L. The TCE and PCE mass occurs at depths greater than 30 feet bgs. No Site-related contaminants were detected in upgradient groundwater screening locations.

1,1-DCE Plume

This plume is near the Maunabo #4 supply well, and is characterized by exceedances of 1,1-DCE. 1,1-DCE was detected at four locations northwest of the Maunabo #4 supply well and exceeded its screening criterion in three locations. The maximum concentration detected was in location GS-L2, with 25 µg/L of 1,1-DCE at 76 to 80 feet bgs. Concentrations increased with depth at three locations, with the highest concentrations occurring in the deepest samples at two locations. 1,1-DCE was not detected in T1-J,which bounds the plume to the east. No Site-related contaminants were detected in upgradient groundwater screening locations.

Monitoring Well and Supply Well Results

Two rounds of groundwater samples were collected from Maunabo #1 and Maunabo #4 supply wells, and the 16 RI monitoring wells. No exceedances of Site-related contaminants were found in the Maunabo #1 or Maunabo #4 supply wells. Historically, Site-related contaminants such as PCE, TCE, cis-1,2-DCE, and 1,1-DCE have been documented in the Maunabo #1 supply well since at least 2002. PRASA provided data from regular monitoring starting in 2006, and this data is presented as Figure 1-2. Since 2006, this well has shown a decreasing trend of PCE, TCE, cis-1,2-DCE, and 1,1-DCE levels. 1,1-DCE has historically been detected at levels below the MCL in the Maunabo #4 supply well (Figure 1-3). Site-related contaminants were detected in the other monitoring wells as described below. Results are depicted on cross sections and box maps, included as Figures 1-4 through 1-10.

cis-1,2-DCE Plume

The data indicate that an initial release of Site-related contaminants occurred in or around the PRB facility. The release was most likely comprised of PCE and potentially TCE. These parent compounds have degraded in the subsurface into their breakdown products. The majority of mass in the plume is now present as cis-1,2-DCE. Much lower masses of the degradation byproducts 1,1-DCE, and VC are also present. Only traces of the original TCE and PCE remain in the deeper intervals of the aquifer. Maximum detected concentrations of cis-1,2-DCE and VC were 300 µg/L and 1.8 µg/L , respectively.

The plume is migrating toward the southwest, influenced by regular and consistent pumping in the Maunabo #1 supply well and by the general groundwater flow direction toward the Rio Maunabo. No Site-related compounds were detected above the RI screening criteria in the Maunabo #1 supply well during the two rounds of sampling in the RI. However, Site-related compounds have been detected regularly by PRASA in this well since at least 2002 (Figure 1-2). The plume is bounded potentiometrically upgradient by MW-D, downgradient by Maunabo #1, and laterally by groundwater screening locations T1-A and T1-E.

PCE Plume

It appears that a smaller release of PCE and potentially TCE may have occurred in the FSM area. Once the contaminant mass of the release contacted groundwater, the mass migrated northeast in the aquifer under the influence of pumping in the Maunabo #1 supply well and by the general groundwater flow direction toward the Rio Maunabo. The plume in this area is relatively dilute. The only exceedances of the RI screening criteria were PCE (screening criterion of 5 µg/L) which was detected at a concentration of 8.5 µg/L in monitoring well MW-FD and 7.4 µg/L in one depth interval from groundwater screening location T4-B. This plume is bounded upgradient by MW-H. The downgradient edge of the plume is defined by the Maunabo #1 supply well. The lateral extent of the plume has not been defined.

1,1-DCE Plume

A plume of 1,1-DCE is present in the area northwest of the Maunabo #4 supply well. The greatest concentration (25 µg/L) was detected during Round 2 in monitoring well MW-L. Similar concentrations were detected in nearby wells MW-N and MW-M. 1,1-DCE was detected one order of magnitude lower (1.1 µg/L) in the Maunabo #4 supply well.

It appears that the source of the plume is in the vicinity of MW-L. Groundwater screening was conducted within 400 feet of either side of MW-L. Screening samples collected west of MW-I exhibited no 1,1-DCE; samples east of the well exhibited low concentrations of 1,1-DCE (1.5 µg/L). The downgradient edge of the plume, the zone where 1,1-DCE concentrations are greater than the screening criterion, has not been delineated. Groundwater elevation monitoring conducted at MW-M showed that it is being influenced by pumping in Maunabo #4. The 1,1-DCE plume appears to be sinking as it travels downgradient. Continued pumping from Maunabo #4 is likely to continue to draw a portion of the plume mass into this supply well.

Other Groundwater Contaminants

Low levels of MTBE and benzene were detected in the three areas, as well as in the vicinity of the Total Gas Station, indicating that a gasoline release(s) has occurred. In the two locations where they exceeded screening criteria, benzene and MTBE were no more than 1 µg/L above their respective screening criteria. Non-Site-related organic contaminants detected sporadically and at levels slightly above criteria are considered insignificant. Several metals exceeded the screening criteria, although they are likely due to naturally-occurring minerals and not indicative of a metals-contamination source or iron or manganese reducing conditions in groundwater.

Potential Source Area Soil Results

No Site-related contaminants were detected in soil samples collected from the PRB and the FSM potential source areas targeted in the RI. Therefore, the sampled areas do not appear to be current sources of groundwater contamination in the Maunabo public supply wells. A limited number of semi-volatile organic compounds (SVOCs) were detected at levels slightly exceeding screening criteria, but are not considered significant. Several metals exceeded screening criteria in both areas; however several of them are naturally-occurring soil nutrients (potassium, calcium, and manganese) or were not found at levels indicating a contaminant source.

Surface Water, Sediment, and Porewater Results

Site-related contaminants were not detected in the surface water, sediment, or porewater samples collected from the Rio Maunabo. When considered alongside the determination that the Rio Maunabo is only occasionally a gaining river, the conclusion is that contaminated groundwater is not impacting the Rio Maunabo.

1.9 Contaminant Fate and Transport

In general, VOCs were the most commonly detected contaminants; this includes the Site-related compounds PCE, TCE, cis-1,2-DCE, 1,1-DCE, and VC. VOCs are very soluble in groundwater and have relatively moderate to high vapor pressure; they tend to have a long residence time in groundwater. Observed concentrations do not indicate the presence of non-aqueous phase liquid at the Site.

The fate of a chemical in the environment is a function of its physical and chemical properties and conditions at the Site. The potential for environmental transport is a function of the conditions at the Site, including geological and hydrogeological characteristics. The primary fate and transport aspects of the Site are summarized below.

- The greatest potential for the transport of the Site-related VOCs is through groundwater migration. Site-related VOCs are volatile and generally do not adhere to soil or sediment. As such, they have migrated through the soil from source areas to the water table and down into the groundwater.

- Several types of data at the cis-1,2-DCE plume provide significant evidence that PCE concentrations are decreasing naturally via reductive dechlorination. Evidence includes the presence of biodegradation daughter products such as cis-1,2-DCE and VC, high chloride concentrations, methanogenic conditions, and concentrations of PCE, TCE, cis-1,2-DCE, and 1,1-DCE consistently below the PRGs at Maunabo #1.

- The 1,1-DCE plume is currently in an anoxic denitrifying condition that may not support anaerobic degradation of 1,1-DCE to VC and ethane.

- Anaerobic reductive dechlorination of PCE in the PCE plume is very limited.

- Although extensive dechlorination has occurred within the cis-1,2-DCE plume, complete dechlorination has yet to occur, as indicated by the cis-1,2-DCE, 1,1-DCE, and VC remaining in that plume. This may be attributable to the lower degradation rates of cis-1,2-DCE and VC, and the lack of sufficient organic carbon to support complete and sustainable reductive dechlorination of chlorinated VOCs year round.

Monitored Natural Attenuation Evaluation

The three plumes at the Site show three distinctive profiles of chemical concentrations in relation to monitored natural attenuation (MNA) parameters. Each of these plumes is discussed below.

cis-1,2-DCE Plume

This plume shows several key characteristics for a major loss of PCE by reductive dechlorination as described below.

- No parent compounds such as PCE and TCE were detected immediately downgradient of the potential source area.
- Degradation intermediates such as cis-1,2-DCE, 1,1-DCE, and VC are present in the groundwater.
- There is evidence of anaerobic processes where dechlorination was occurring under methanogenic conditions, as indicated by methane and iron (Fe)(II) production, coinciding with decreasing nitrate concentrations in the area of relatively high levels of cis-1,2-DCE and VC.
- PCE, TCE, cis-1,2-DCE, and 1,1-DCE concentrations at Maunabo #1 have been primarily below the PRGs from 2006 to 2011.
- Chloride concentrations greater than those detected within background well MW-D were present at some locations.

The data indicate that the methanogenic conditions normally accompanying reductive dechlorination are present in the shallow groundwater in an area immediately downgradient of the potential source (i.e., MW-B) and extend to the general area of locations MW-AS and MW-K.

PCE Plume

The lack of PCE biodegradation intermediate compounds such as cis-1,2-DCE and VC, and the generally unfavorable geochemical characteristics of the groundwater (i.e., relatively aerobic conditions and low levels of Fe(II) concentrations) indicate that subsurface conditions are unlikely to support biodegradation. The lack of primary substrate to drive reducing conditions and drive dechlorination of PCE and TCE explains why the plume is not being attenuated by anaerobic biodegradation.

1,1-DCE Plume

This plume shows evidence of an anoxic denitrifying condition, which may be insufficient to support degradation of DCE to VC and ethene. However, more aerobic conditions are expected to occur downgradient of the plume. Since 1,1-DCE and its daughter product VC are known to be degradable by aerobic bacteria, biodegradation would be expected to occur over time as the plume migrates downgradient.

1.10 Conceptual Site Model

The CSM is developed to integrate all the different types of information collected historically and during the RI, including the Site physical setting, the nature and extent of contamination, and contaminant fate and transport.

The Site is within the Rio Maunabo valley, with the Rio Maunabo as the major surface water drainage path. The direction of groundwater flow at the Site is mainly influenced by two factors: the Rio Maunabo and the pumping of the two public water supply wells, Maunabo #1 and Maunabo #4. In general, groundwater flows toward these three site features.

Site-related contaminants are generally deep in the aquifer, and were not detected in the surface water, sediment, or porewater samples collected from the Rio Maunabo. Rio Maunabo is only occasionally a gaining river. The conceptual model is that contaminated groundwater is not impacting the Rio Maunabo.

There are three groundwater contaminant plumes at the Site, most likely emanating from limited and separate releases of chlorinated solvents. The plume near the PRB facility is mostly comprised of cis-1,2-DCE. Since a very limited amount of PCE and TCE was found in this plume, the data indicate that there is no continuing discharge of Site-related contaminants to this plume, and that the plume has been in the subsurface for some time. The southwestern plume near the FSM is mostly comprised of PCE. The concentrations are very dilute, marginally exceeding the groundwater screening criteria. Although degradation byproducts were not encountered here, a continuing source of contamination is not expected in this area because the amount of contaminant mass in the subsurface is low, and Site-related contaminants were not detected in soil samples from the area. The cis-1,2-DCE and PCE plumes are impacting the Maunabo #1 supply well. The third plume is located to the north of Maunabo #4 and consists almost entirely of 1,1-DCE. Concentrations are relatively dilute, making it unlikely that there is a continuing upgradient source of contamination.

The most important pathway for the movement of contamination at the Site is transport in groundwater. The cis-1,2-DCE plume is being pulled southwest by the induced groundwater gradient from pumping in the Maunabo #1 supply well and by natural groundwater flow toward the Rio Maunabo. The PCE plume follows the natural and induced groundwater gradients toward the Rio Maunabo and Maunabo #1. The 1,1-DCE plume is more dispersed, being pulled to the south-southeast by the induced gradient of pumping in Maunabo #4 and toward the south-southwest by the natural groundwater gradient toward the Rio Maunabo.

Contaminant concentrations on the leading edge of the plumes are lower than those found in areas that are in the potentiometrically upgradient portion of each plume. This decrease in concentration is primarily due to a combination of dilution, dispersion, and degradation. No soil vapor data was collected during the RI; however there appears to be little risk of significant accumulation of vapors at the Site. Volatilization is unlikely to be a significant factor, primarily because the contamination is relatively deep in the aquifer, and is far removed from the vadose zone where contaminants could volatilize into air-filled voids.

Since no evidence was identified to indicate that the Rio Maunabo is being impacted by Site contamination, the principal receptors at the Site are users of groundwater from the Maunabo #1 and #4 supply wells.

Maunabo #1 is screened in a bedrock valley. As a result of this hydrogeology and pumping from this supply well, contaminants from the PCE plume and the cis-1,2-DCE plume have been identified in Maunabo #1. Recent (RI Rounds 1 and 2) contaminant concentrations in Maunabo #1 are below the MCLs. Analysis of historical data collected by PRASA (Figure 1-2) shows that concentrations of PCE, TCE, cis-1,2-DCE, and 1,1-DCE have primarily been below PRGs in Maunabo #1. Dilution, dispersion, and biodegradation are all likely contributing factors to the observed trends. Concentrations of the four contaminants are expected to remain low. However, VC is being produced intermittently from the biodegradation of cis-1,2-DCE. As a result, the potential exists for VC to be detected in Maunabo #1 in the future.

1,1-DCE has been detected in the Maunabo #4 supply well, but at concentrations well below the MCL (Figure 1-3). The native geology is such that a component of the groundwater gradient is towards the Rio Maunabo, meaning that pumping in Maunabo #4 only draws a fraction of the plume into this supply well. Furthermore, it is evident from the groundwater screening data that the plume has sunk through the aquifer to approximately the level of bedrock. The slope of bedrock is influencing the migration path of the plume. Unlike the area around Maunabo #1, the bedrock at the 1,1-DCE plume does not funnel directly towards the supply well, but instead slopes towards Rio Maunabo. In effect, the Maunabo #4 well is more cross-gradient to the 1,1-DCE plume than downgradient. As a result of this hydrogeology, higher concentrations of 1,1-DCE or its breakdown products are not expected in Maunabo #4 in the future.

1.11 Cultural Resource Survey

In October 2011, the Stage 1A level Cultural Resources Survey was completed by Richard Grubb & Associates, Inc. (RGA) on and around the Site. RGA evaluated the potential for any historical, architectural, or archaeological resources that might be impacted by the project activities and determined the probability that archaeological resources were present within the project area. The area of potential effects (APE) is a 375 acre area in the municipality of Maunabo. The ruins of a historic sugar mill and a prehistoric and Colonial-Period Site were indentified within and near the APE boundary. The southeastern portion of APE possesses a high sensitivity for archeological resources associated with another historic Site (Hacienda Bordelese). Much of the remaining Site area, including the densely developed downtown area, has low potential for archeological resources. RGA recommended that a Stage 1B archeological survey be conducted if subsurface disturbance associated with remediation is planned in areas identified as having high to moderate archeological sensitivity.

Section 2

Development of Remedial Action Objectives and Screening of Technologies

RAOs are media-specific goals for protecting human health and the environment. They serve as guidance for the development of remedial alternatives. The RAOs are based on regulatory requirements and risk based evaluations, which may apply to the various remedial activities being considered for the Site.

The process of identifying the RAOs is summarized below.

- The identification of affected media and contaminant characteristics
- The evaluation of exposure pathways, contaminant migration pathways, and exposure limits
- The evaluation of chemical concentrations that will result in unacceptable exposure

PRGs are target chemical concentrations that the remedial action needs to achieve in order to protect human health and the environment. PRGs were selected based on Federal or Commonwealth promulgated ARARs, risk-based levels, and background concentrations, with consideration also given to other requirements such as analytical detection limits and guidance values. These PRGs were then used as a benchmark in the technology screening, alternative development and screening, and detailed evaluation of alternatives presented in the subsequent sections of the FS report.

2.1 Identification of Remedial Action Objectives

Contaminated groundwater is the media of interest for the Maunabo Site. Surface and subsurface soil samples collected during the RI did not identify a source of Site-related VOCs. Site related contaminants are chlorinated aliphatic compounds, including PCE, TCE, cis-1,2-DCE, 1,1-DCE, and VC. These contaminants are VOCs and may pose risks to human health through inhalation, ingestion, and dermal contact.

Based on the groundwater data collected during the RI, there are three separate plumes at the Site. These three plumes are located in different areas of the Site and have characteristic contaminant profiles. The cis-1,2-DCE plume is located between the PRB facility and the Maunabo #1 public supply well. The PCE plume is located between the FSM and the Maunabo #1 public supply well. The 1,1-DCE plume is located northwest of the Maunabo #4 public supply well. The groundwater plumes are within a designated Wellhead Protection Area and the public supply wells (Maunabo #1 and Maunabo #4) are currently in operation.

The RAOs for the Site are:

- Protect human health by preventing exposure via ingestion, inhalation, or dermal contact to contaminated groundwater with concentrations above PRGs
- Remediate the groundwater to its most beneficial use as a potable water supply by reducing site contaminant concentrations to PRGs.

2.2 Potential ARARs, Guidelines, and Other Criteria

As required under Section 121 of CERCLA, remedial actions carried out under Section 104 or secured under Section 106 must be protective of human health and the environment and attain the levels or standards of control for hazardous substances, pollutants, or contaminants specified by the ARARs of Federal environmental laws and Commonwealth environmental and facility siting laws, unless waivers are obtained. According to EPA guidance, remedial actions also must take into account non-promulgated “to be considered” (TBC) criteria or guidelines if the ARARs do not address a particular situation.

The degree to which these environmental and facility siting requirements must be met varies, depending on the applicability of the requirements. Applicable requirements must be met to the full extent required by law. CERCLA provides that permits are not required when a response action is taken on-Site. The National Contingency Plan (NCP) defines the term on-Site as the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for the implementation of the response action (40 Code of Federal Regulations [CFR] 300.5). Although permits are not required, the requirements of the applicable permits will be met. On the other hand, only the relevant and appropriate portions of non-applicable requirements must be achieved, and only to the degree that they are substantive rather than administrative in nature.

CERCLA requires that on-Site remedial actions attain or waive Federal environmental ARARs, or more stringent Commonwealth environmental ARARs, upon completion of the remedial actions. The purpose of ARARs is to define the minimum level of protection that must be provided by a remedy selected and implemented. Additional protection may be required, if necessary, to protect human health and the environment.

2.2.1 Definition of ARARs

Under CERCLA, as amended, a Federal or Commonwealth promulgated requirement may be either “applicable” or “relevant and appropriate” to a Site-specific remedial action, but not both. The distinction is critical to understand the constraints imposed on remedial alternatives by environmental regulations other than CERCLA.

2.2.1.1 Applicable Requirements

Applicable requirements pertain to those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental, Commonwealth environmental, or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those Commonwealth standards that are more stringent than Federal requirements may be applicable. Applicable requirements are defined in the NCP, at 40 CFR 300.5—Definitions.

2.2.1.2 Relevant and Appropriate Requirements

Relevant and appropriate requirements pertain to those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental, Commonwealth environmental, or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site per se, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. Relevant and appropriate requirements are defined in the NCP, at 40 CFR 300.5—Definitions.

The determination that a requirement is relevant and appropriate is a two-step process that includes: (1) the determination if a requirement is relevant and (2) the determination if a requirement is appropriate. In general, this involves a comparison of a number of Site-specific factors, including an examination of the purpose of the requirement and the purpose of the proposed CERCLA action, the medium and substances regulated by the requirement and the proposed requirement, the actions or activities regulated by the requirement and the remedial action, and the potential use of resources addressed in the requirement and the remedial action. When the analysis results in a determination that a requirement is both relevant and appropriate, such a requirement must be complied with to the same degree as if it were applicable (EPA 1988).

2.2.1.3 Other Requirements to Be Considered

These requirements pertain to Federal and Commonwealth criteria, advisories, guidelines, or proposed standards that are not generally enforceable but are advisory and that do not have the status of potential ARARs. Guidance documents or advisory TBCs may be used where no specific ARARs exist for a chemical or situation, or where such ARARs are not sufficient to be protective, to determine the necessary level of remediation to be protective of human health or the environment.

2.2.1.4 Classification of ARARs

Three classifications of requirements are defined by EPA in the ARAR determination process. ARARs are defined as chemical-, location-, or action-specific. Additionally, TBC criteria are also evaluated. TBC criteria are not federally enforceable standards but may be technically or otherwise appropriate to consider in developing Site- or media-specific PRGs.

Chemical-specific ARARs and TBCs

Chemical-specific ARARs include those laws and regulations governing the release of materials possessing certain chemical or physical characteristics, or containing specified chemical compounds. These ARARs and TBCs usually are numerical values that are health- or risk-based values or methodologies. They establish acceptable amounts or concentration of chemicals that may be found in, or discharged to, the ambient environment. They also may define acceptable exposure levels for a specific contaminant in an environmental medium. They may be actual concentration-based cleanup levels, or they may provide the basis for calculating such levels. Examples of chemical-specific ARARs are polychlorinated biphenyl cleanup criteria for soils under the Toxic Substances and Control Act or

MCLs specified for public drinking water that are applicable to groundwater aquifers used for drinking water.

Location-specific ARARs and TBCs
Location-specific ARARs are design requirements or activity restrictions based on the geographical or physical positions of the Site and its surrounding area. Location-specific requirements set restrictions on the types of remedial activities that can be performed based on Site-specific characteristics or location. Examples include areas in a floodplain, a wetland, or a historic site. Location-specific criteria can generally be established early in the RI/FS process since they are not affected by the type of contaminant or the type of remedial action implemented.

Action-specific ARARs and TBCs
Action-specific ARARs are technology-based, establishing performance, design, or other similar action-specific controls and restriction to particular remedial actions. These action-specific ARARs are considered in the screening and evaluation of various technologies and process options in subsequent sections of this report.

ARARs and TBCs identified for each type are provided in Sections 2.2.2 to 2.2.4. Summaries of the potential ARARs and TBCs criteria are provided in Tables 2-1 through 2-3.

2.2.2 Chemical-specific ARARs and TBCs

Table 2-1 summarizes the chemical specific ARARs and TBCs identified for this Site. Federal Standards and Guidelines

Federal Drinking Water Standards and Regulations

- National Primary Drinking Water Standards (40 CFR 141). Groundwater at the Site is currently used as a source of drinking water. Federal primary drinking water standards are relevant and appropriate requirements to accommodate for current and future use of Site groundwater as a drinking water source.

Commonwealth Standards and Guidelines

Puerto Rico Water Quality Standards (PRWQS) Regulation

- PRWQS (March 2010). The purpose of the PRWQS is to preserve, maintain, and enhance the quality of waters of Puerto Rico and prohibit any discharge of any pollutant to the waters of Puerto Rico by establishing water quality standards. Under the regulation, the "waters of Puerto Rico" include all coastal waters, surface waters, estuarine waters, ground waters and wetlands. However, since all of the remedial alternatives being considered at the Site do not entail any discharges to any waters of Puerto Rico, EPA has determined that the PRWQS are neither applicable nor relevant or appropriate to these remedies.

2.2.3 Location-Specific ARARs

Location-specific ARARs are those relevant to wetlands, flood plains, historical places, archaeological significance, endangered species, and wildlife habitats. The Site is situated within the floodplain of the Maunabo River, which flows from west to southeast (RGA 2012). Land use is primarily agricultural intermixed with some residential, commercial, and light industries. The Site has no wildlife habitat. No known threatened, endangered species/sensitive environments are in close proximity to the Site (CDM Smith 2012b). Table 2-2 summarizes the location-specific ARARs for this Site.

Federal Standards and Guidelines

- Statement on Procedures on Floodplain Management and Wetlands Protection (40 CFR 6, Appendix A)
- Policy on Floodplains and Wetland Assessments for CERCLA Actions (Office of Solid Waste and Emergency Response [OSWER] Directive 9280.0-12, 1985)
- Wetlands Executive Order (EO 11990)
- National Environmental Policy Act (NEPA) (42 USC 4321; 40 CFR 1500 to 1508)
- Clean Water Act (CWA) Section 404 (40 CFR 404
- National Historic Preservation Act (40 CFR 6.301

Commonwealth of Puerto Rico Standards and Guidelines

- Act for the Protection and Preservation of Puerto Rico's Karst Region, August 21, 1999, No. 292

2.2.4 Action-specific ARARs and TBCs

Action-specific ARARs affect the implementation of specific remedial technologies. For example, although outdoor air has not been identified in the RI report as a contaminated medium of concern, air quality ARARs are listed below because some potential remedial actions may result in air emissions of toxic or hazardous substances. Table 2-3 summarizes the action-specific ARARs for this Site.

Federal Standards and Guidelines

General - Site Remediation

- Occupational Safety and Health Administration (OSHA) Worker Protection (29 CFR 1904, 1910, 1926)
- OSHA General Industry Standards (29 CFR 1910)
- OSHA Construction Industry standards (29 CFR 1926)
- Resource Conservation and Recovery Act (RCRA): Identification and Listing of Hazardous Waste (40 CFR 261); Standards Applicable to Generators of Hazardous Waste (40 CFR 262); Standards for Owners/Operators of permitted hazardous waste facilities (40 CFR 264.10-264.19)

Transportation of Hazardous Waste

- Department of Transportation (DOT) Rules for Transportation of Hazardous Materials (49 CFR 107, 171, 172, 177, and 179)
- RCRA Standards Applicable to Transporters of Hazardous Waste (40 CFR 263)

Waste Disposal

- RCRA Land Disposal Restrictions (40 CFR 268)
- RCRA Hazardous Waste Permit Program (40 CFR 270)

Discharge of Groundwater or Subsurface Injection

- Federal CWA - National Pollutant Discharge Elimination System (NPDES) (40 CFR 100 et seq.)
- Federal Safe Drinking Water Act - Underground Injection Control (UIC) Program (40 CFR 144, 146)

Off-Gas Management

- Clean Air Act (CAA) - National Ambient Air Quality Standards (NAAQS) (40 CFR 50)
- Standards of Performance for New Stationary Sources (40 CFR 60)
- National Emission Standards for Hazardous Air Pollutants (40 CFR 61)
- Federal Directive – Control of Air Emissions from Superfund Air Strippers (OSWER Directive 9355.0-28)

Commonwealth of Puerto Rico Standards and Guidelines

General – Site Remediation

- PREQB Regulation for the Prevention and Control of Noise Pollution
- Puerto Rico's Anti-degradation Policy

Waste Disposal

- PREQB Regulation for the Control of Non-Hazardous Solid Waste (November 1997)
- PREQB Regulation for the Control of Hazardous Solid Waste (September 1998)

Discharge of Groundwater or Subsurface Injection

- PRWQS Regulation , March 2010

Off-Gas Management

- PREQB Regulation for the Control of Atmospheric Pollution (1995)

2.3 Preliminary Remediation Goals

Federal MCLs are the relevant and appropriate chemical-specific ARARs for the contaminated groundwater at the Site. Groundwater at the Site is classified as SG, suitable for drinking water use, and it is currently utilized as a source of potable water supply. Therefore, federal drinking water standards are applicable requirements. PRGs, which are the groundwater cleanup goals, have been derived from chemical-specific ARARs for this Site, and are presented in Table 2-4.

Even though the PRGs are the ultimate concentration goals for Site cleanup, Site-specific situations and limitations on currently available technologies may prevent the remedial action to achieve the PRGs within a reasonable time frame. Additionally, most remedial technologies are capable of reducing contaminant mass, but are not cost-effective to remediate low level groundwater contamination as seen in the PCE plume with concentrations less than 10 µg/L. Natural attenuation is usually the cost-effective alternative to achieve PRGs in such low concentration plumes via destructive and non-destructive mechanisms such as dilution, dispersion and degradation. These constraints are further discussed in Section 2.6 and in Section 3.

2.4 Identification of Remediation Area

Six Site-related contaminants are identified in Table 2-4. The three most widely detected contaminants, PCE, cis-1,2-DCE, and 1,1-DCE, are used as the indicator contaminants (ICs) to define the Site-specific cleanup areas. These three contaminants are also detected at concentrations exceeding PRGs and are, therefore, used as the ICs for technology evaluation.

Based on the contaminant concentrations, three distinct plumes have been identified at the Site as discussed previously in Section 1.0. The vertical extents of contamination within these areas with concentrations that exceed the PRGs are the zones that would require remediation. However, actively remediating areas with low contaminant concentrations may not be practical or cost effective. The approximate areal extent of each plume is shown in Figure 2-1 and is discussed in Section 2.4.1.

2.4.1 Contaminant Plumes

The three contaminant plumes that would require remediation are defined and described below. Each plume was defined based on the concentration of the most widely detected contaminant exceeding its PRG in the groundwater. Figure 2-1 shows the contaminant plumes in plan view, and Figures 1-5 through 1-8 show cross sections of the plumes.

- The cis-1,2-DCE contaminant plume includes the area with the highest contaminant concentrations in the groundwater: cis-1,2-DCE at 300 µg/L, VC at 1.8 µg/L and trace levels of TCE, and 1,1-DCE. This plume is located between the PRB facility and the Maunabo #1 public supply well. The treatment zone is considered to be the groundwater with cis-1,2-DCE concentrations above the PRG (70 µg/L). The thickness of the treatment zone is approximately 15 feet. The areal extent of the treatment zone is approximately 85,000 square feet. Assuming a porosity of 0.3, and conservatively assuming that the maximum concentration of cis-1,2-DCE detected (300 µg/L) represents the average concentration across the entire volume of the plume, then the total dissolved mass of cis-1,2-DCE in the plume is calculated to be 3.25 kilograms (kg).

- The 1,1-DCE contaminant plume includes the area with the highest contaminant concentrations in the groundwater: 1,1-DCE at 25 µg/L and trace levels of cis-1,2-DCE. This plume is located northwest of the Maunabo #4 public supply well. The treatment zone is considered to be the groundwater with 1,1-DCE concentrations above the PRG (7 µg/L). The thickness of the treatment zone is approximately 25 feet. The areal extent of this plume is approximately 110,000 square feet, although the downgradient limit of the plume has not been fully delineated. Assuming a porosity of 0.3, and conservatively assuming that the maximum concentration of 1,1-DCE detected (25 µg/L) represents the average concentration across the entire volume of the plume, then the total dissolved mass of 1,1-DCE in the plume is calculated to be 0.58 kg.

- The PCE contaminant plume includes the area with PCE at 8.5 µg/L and trace levels of TCE, 1,1-DCE, and cis-1,2-DCE. This plume is located between the FSM area and the Maunabo #1 public supply well. The treatment zone is considered to be the groundwater with PCE concentrations above the PRG (5 µg/L). The thickness of the treatment zone is approximately 10 feet and the areal extent is approximately 30,000 square feet. Assuming a porosity of 0.3, and conservatively assuming that the maximum concentration of PCE detected (9 µg/L) represents the average concentration across the entire volume of the plume, then the dissolved mass of PCE in the plume is calculated to be 0.02 kg.

As defined above, these treatment areas are used in discussions of the effectiveness and costs of various remedial technologies in Section 2.6. Remedial technologies suitable for treating low contaminant mass or monitoring low contaminant concentrations will be used to target the contaminant plumes at the Site.

2.5 General Response Actions

GRAs are broad categories of remedial actions that may satisfy the RAOs. Following the description of GRAs, one or more remedial technologies and process options were identified for each GRA category. Usually an individual technology and process option is not capable of satisfying the RAOs alone. Combinations of technologies and process options under different GRAs are frequently required to address Site contamination adequately to meet the RAOs and the PRGs. GRAs applicable to this Site are described below.

2.5.1 No Action

The NCP and CERCLA require the evaluation of a No Action alternative as a basis for comparison with other remedial alternatives. Under the No Action response, no remedial actions are implemented, the current status of the Site remains unchanged, and no action would be taken to reduce the potential for exposure to contamination. While the No Action response action may include environmental monitoring, it does not include any actions (e.g., institutional controls) to protect human health or the environment.

2.5.2 Institutional/Engineering Controls

Institutional controls typically are restrictions placed to prevent certain types of uses (e.g., deed restrictions) or future use of the Site (e.g., well drilling restrictions). Engineering controls consist of installation of engineering systems to prevent or reduce the exposure to Site contaminants, such as public water supply management. They also include public education and/or groundwater use restrictions. These limited measures are implemented to provide some protection of human health from exposure to Site contaminants. Long-term monitoring, which includes routine sampling and analyses, is usually used with institutional/engineering controls to monitor contaminant migration, and provide information for institutional/ engineering controls decisions. Institutional/engineering controls and long-term monitoring are generally used in conjunction with other remedial technologies; alone they are not effective in preventing contaminant migration or reducing the level of contamination.

2.5.3 Monitored Natural Attenuation

MNA refers to the remedial action that relies on naturally occurring attenuation processes to achieve Site-specific remediation goals within a reasonable time frame. Natural attenuation processes that reduce contaminant concentrations in groundwater include destructive (biodegradation and chemical reactions with other subsurface constituents) and nondestructive mechanisms (dilution, dispersion, volatilization, and adsorption). Sites where the contaminant plume is no longer increasing in extent, or where the contaminant concentrations are decreasing, are most appropriate for MNA consideration (without other GRAs). Routine monitoring and contaminant concentration trend analysis are generally performed as part of the MNA response action to demonstrate that contaminants do not represent significant risk and that degradation is occurring.

2.5.4 Containment

Containment response actions use physical barriers (such as slurry walls and sheet piling) to minimize or eliminate contaminant migration. It is usually used at the source area. Containment technologies do not involve treatment to reduce the toxicity or volume of the contaminants at the Site and require long-term monitoring to determine whether containment measures are performing successfully. Hence, this GRA is typically combined with other response actions in order to assess the effectiveness. The NCP does not prefer containment response actions since they do not provide permanent remedies.

2.5.5 Groundwater Extraction

Groundwater extraction provides hydraulic control to prevent migration of dissolved contaminants. Groundwater extraction is typically combined with ex-situ treatment and discharge response actions to achieve the RAOs. Groundwater extraction response actions provide reduction in mobility and mass of contaminants by removing the contaminants from the subsurface using groundwater extraction wells or interceptor trenches.

2.5.6 Treatment

Treatment of contaminated groundwater includes both in-situ (e.g., bioremediation, air sparging, thermal remediation, chemical reduction, and chemical oxidation) and ex-situ treatment technologies (e.g., air stripping, activated carbon adsorption, and advanced oxidation).

Treatment response actions reduce the T/M/V of contaminants and afford a higher degree of protection to public health and the environment. The use of treatment technologies to achieve RAOs is favored by CERCLA, unless Site conditions limit their application.

2.5.7 Discharge

Discharge response actions for groundwater involve the discharge of treated groundwater via on-Site injection, on-Site surface recharge, or surface water discharge. The discharged water must meet regulatory discharge requirements.

2.6 Identification and Screening of Remedial Technologies and Process Options

For each GRA, technologies and process options potentially capable of addressing groundwater contamination at the Site are identified and screened in this section. Representative remedial technologies and process options that are retained will be used to develop remedial action alternatives in Section 3, either alone or in combination with other technologies. Table 2-5 presents the summaries of technology screening for the three plumes.

The technology screening approach is based upon the procedures outlined in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). The evaluation process uses three criteria: effectiveness, implementability, and relative cost. Among these three, the effectiveness criterion outweighs the implementability and relative cost criteria. These criteria are described below.

<u>Effectiveness</u>: This evaluation criterion focuses on the effectiveness of process options to reduce the toxicity, mobility, or volume of contamination for long-term protection and for meeting the RAOs and PRGs. It also evaluates the potential impacts to human health and the environment during construction and implementation, and how proven and reliable the process is with respect to Site-specific conditions. Technologies and process options that are not effective due to Site-specific settings are eliminated by this criterion.

<u>Implementability</u>: This evaluation criterion encompasses both the technical and administrative feasibility of the technology or process option. It includes an evaluation of pretreatment requirements, remedial construction requirements, residuals management, the relative ease or difficulty in performing the operation and maintenance (O&M), the availability of qualified vendors, etc. Technologies and process options that are clearly not implementable at the Site are eliminated by this criterion. Site-specific constraints that can limit the implementation of remedial actions are also considered. The cis-1,2-DCE plume is migrating toward the southwest and extends beneath State Road PR-3 which is to the south of the PRB facility. This road is at least 30 feet wide. Access to the contaminants underneath the road for remediation might be impractical. Remediation within this road is not considered implementable due to access considerations. Remediation will be considered on both sides of the road as necessary but not within the road.

<u>Relative Cost</u>: Cost plays a limited role in the screening process. Both capital and O&M costs are considered. The cost analysis is based on engineering judgment, and each process is evaluated as to whether costs are low, medium, or high, relative to the other options within the same GRA type.

2.6.1 Long-Term Monitoring

Long-term monitoring includes periodic sampling and analysis of groundwater. The monitoring program provides an indication of the progress of remedial activities and contaminant migration post active treatment. Data collected by the long-term monitoring program would be used in five-year reviews.

Effectiveness: Long-term monitoring alone would not be effective in reducing contamination levels. It would not alter the risk to human health or the effect on the environment. However, natural attenuation processes such as dilution, dispersion, biodegradation, and volatilization would decrease groundwater contaminant concentrations and therefore potentially decrease the toxicity. Long-term monitoring would be effective in providing information on Site conditions to decision makers for all contaminant plumes. Data for the natural attenuation evaluation would also be collected in a long-term monitoring program for the evaluation of MNA.

Implementability: Groundwater monitoring is a proven and reliable process, and could be easily implemented. A comprehensive monitoring well network would need to be installed for the long-term monitoring program.

Relative Cost: Long-term monitoring would involve medium capital cost if the monitoring well network would need to be established by installation of wells and medium O&M costs.

Conclusion: Long-term monitoring is retained for all three plumes.

2.6.2 Institutional/Engineering Controls

Institutional/Engineering Controls do not reduce the T/M/V of contamination, but can be implemented to reduce the probability of exposure to contaminants. Institutional controls consist of administrative actions which control use of the Site (e.g., deed restriction), and community educational programs to increase awareness about contamination on the Site. Engineering controls consist of installation of engineering systems to prevent or reduce the exposure to Site contaminants, such as public water supply management. Institutional/Engineering Controls generally would require long-term monitoring of contaminant concentrations. Typical Institutional/Engineering Controls are discussed below.

2.6.2.1 Deed Restrictions

Deed restrictions are local administrative actions that are used to prevent certain types of uses for properties where exposure pathways to contaminants may be created as a result of those uses. Deed restrictions may be used to require the installation of a vapor mitigation system; or prevent well drilling within the contamination plume. Deed restrictions are generally administrated by the local government.

Effectiveness: Deed restrictions could effectively restrict or eliminate exposure to contaminated groundwater, thereby reducing human health risks posed by the three plumes. The effectiveness of deed restrictions would depend on proper enforcement. Deed restrictions would not reduce the migration and environmental impact of the contaminated groundwater in any of the contaminant areas.

Implementability: Deed restrictions may not be easy to implement. Their implementability would highly depend on the local government and its enforcement system.

Relative Cost: The implementation cost is low. Some administrative, long-term monitoring and periodic assessment costs would be required.

Conclusion: Deed Restrictions are retained for further evaluation for all three plumes.

2.6.2.2 Well Drilling Restrictions

Well drilling restrictions are regulatory actions that regulate the installation of wells. PREQB has the administrative authority to prevent the installation of drinking water wells in the contaminated areas. Drilling of wells for irrigation could also be restricted.

Effectiveness: Well drilling restrictions would be effective for protection of human health by preventing direct contact with contaminated groundwater in all three plumes. Well drilling restrictions would not reduce the migration and environmental impact of the contaminated groundwater in any of the contaminant plumes.

Implementability: Well drilling restrictions could be implemented via the existing permitting process. Well drilling restrictions may be combined with other remediation activities, as a protective measure to prevent future exposure to contaminants during and post remediation.

Relative Cost: The cost to implement well drilling restrictions would be low.

Conclusion: Well drilling restrictions are retained for further evaluation for all three plumes.

2.6.2.3 Public Water Supply Management

The contaminant plumes at the Site are located in the vicinity of public water supply wells Maunabo #1 and Maunabo #4. The public water supply system would be evaluated to identify operating scenarios whereby the groundwater contamination would not impact human health. These scenarios may include taking the wells offline, additional treatment, or alternate supply such as surface water or bottled water.

Effectiveness: Management of the public water supply system would be effective for protection of human health if consumers are exposed to groundwater above the PRGs. It does not directly relate to any specific contaminant plume at the Site. It would not reduce the migration and environmental impact of the contaminated groundwater in any of the contaminant plumes.

Implementability: The public water supply system provides approximately 60 percent of the water needs for the population in Maunabo. Therefore, turning off the public supply wells would not be implementable. Public water supply management may not be implementable if no feasible operating scenarios can be identified.

Relative Cost: Costs will depend upon the operating scenarios.

Conclusion: Public water supply management is not retained for the Site.

2.6.2.4 Community Awareness

Community awareness involves information and education programs to enhance awareness of potential hazards, available technologies that are capable to address the contamination, and the remediation progress to the local community.

Effectiveness: Educational programs would protect human health by creating awareness and would enhance the implementation of deed restrictions within the contaminated aquifer.

Implementability: This option would be implementable.

Relative Cost: Community awareness would have low capital and operational costs.

Conclusion: Community awareness is retained for all three plumes.

2.6.3 Monitored Natural Attenuation

MNA refers to the remedial action that relies on naturally occurring attenuation processes to achieve Site-specific RAOs within a reasonable time frame. Natural attenuation processes that reduce contaminant concentrations in groundwater include destructive (biodegradation and chemical reactions with other subsurface constituents) and nondestructive mechanisms (dilution, dispersion, volatilization, and adsorption).

Dilution reduces contaminant concentrations through mixing of the contaminated plume with non-contaminated groundwater. Dispersion is the process by which a pollutant is spread over a wider area due to local variations in groundwater velocity and flow paths caused by different soil particle sizes in the aquifer. Molecular diffusion describes the contaminant migration due to concentration gradients. Both dispersion and diffusion reduce contaminant concentrations. Volatilization is the process by which contaminants in the liquid phase convert to the gaseous phase, reducing contaminant concentrations in the liquid phase. Adsorption occurs when contaminants adhere to the surface of soil particles. Adsorption would reduce the migration of contaminants. Biodegradation transforms contaminants to different compounds.

Biodegradation to non-toxic compounds is typically the most significant destructive attenuation mechanism. The intermediates and end products of biodegradation can be either non-toxic or more toxic than the original contaminants. The chlorinated solvents PCE and TCE attenuate predominantly by reductive dechlorination under anaerobic conditions. Breakdown products cis-1,2-DCE and VC attenuate under both anaerobic and aerobic conditions. The primary anaerobic reductive dechlorination pathway for PCE to ethene is given below:

PCE → TCE → cis-1,2-DCE → VC → Ethene

Reductive dechlorination is a cometabolic process requiring an adequate supply of electron donors. The existence of other electron acceptors, such as oxygen, nitrate/nitrite, ferric iron, or sulfate can inhibit the dechlorination process. The highest reductive dechlorination rates have been observed under highly reducing conditions associated with methanogenic reactions. If the dechlorination process is inhibited, biodegradation will “stall” at the intermediate daughter compounds cis-1,2-DCE and VC. However, these lesser oxidized chlorinated compounds are amenable to attenuate under aerobic conditions.

By analyzing biogeochemistry data, including the presence and concentrations of organic carbon, the distribution of electron acceptors (e.g., dissolved oxygen, nitrate/nitrite, sulfate) and their reduced species (e.g., ferrous iron, sulfide), degradation intermediates and products, and the contaminant changes over time, it is possible to determine whether active biotransformation of the chlorinated solvents has occurred in the past.

1,1-DCE is also formed through the abiotic degradation of 1,1,1-trichloroethane (1,1,1-TCA), particularly hydrolysis and thermal decomposition. 1,1-DCE can undergo reductive dechlorination and be reduced to vinyl chloride. 1,1-DCE may degrade via aerobic biodegradation. Under anaerobic conditions, 1,1-DCE are slowly biodegraded via reductive dechlorination; however, the extent and rate of degradation are dependent upon the strength of the reducing environment.

Effectiveness: MNA is effective for sites where multiple years of data have demonstrated that the contaminant plume is contained or shrinking; destructive attenuation mechanisms are active and responsible for containing the contaminant plume; and sufficient evidence exists that these attenuation mechanisms would persist for the required time of plume management. Sampling results suggest biodegradation has been occurring in the cis-1,2-DCE plume and abiotic degradation has occurred in the 1,1-DCE plume. This is evident from the fact that no parent compounds such as PCE and TCE were detected in the cis-1,2-DCE plume and no parent compounds such as 1,1,1-TCA and TCE were detected in the 1,1-DCE plume. Under favorable conditions in the cis-1,2-DCE plume, continued biodegradation can be effective in containing and remediating contamination in a reasonable timeframe. However, if reduction-oxidation (redox) conditions become more aerobic as the plume migrates downgradient, aerobic biodegradation would be possible. The redox conditions and very low concentrations of the PCE plume are likely to be conducive to nondestructive attenuation mechanisms like dilution, dispersion, volatilization, and adsorption. Supplemental studies would be required to sufficiently demonstrate the effectiveness of MNA.

Implementability: Materials and services necessary to model and monitor the contaminant dynamics are readily available. Institutional/engineering Controls would be required to minimize human exposure to contaminants. At the Site, MNA would be implemented, alone, in conjunction with active remediation, or as a follow up to a remedial action.

Relative Cost: MNA would require medium capital costs to fully understand the CSM, which would include field investigations, sampling and analyses, groundwater modeling, etc. The O&M costs would be medium for this Site since a selected number of wells would need to be sampled and analyzed periodically and the contaminant migration would need to be evaluated.

Conclusion: MNA is retained for further evaluation in all three plumes.

2.6.4 Containment

Low-permeability barrier walls would be installed downgradient from source areas or plumes to control contaminant migration. The walls would be constructed using slurry or sheet piling to the top of a low permeability layer. Containment technologies would only be effective in areas of the Site where the contamination is at shallow depths on top of a continuous, non-leaky confining clay layer. Within these areas, both types of barrier walls (i.e., slurry or sheet pile) would be effective for containing contaminated groundwater flow. If used in combination with a groundwater extraction system, the walls would also minimize the amount of pumping required to maintain hydraulic control by acting as a physical barrier, restricting clean groundwater inflow from side-gradient areas into the capture zone.

2.6.4.1 Slurry Walls

Slurry walls are constructed by placing low-permeability slurry, typically consisting of either a soil-bentonite or cement-bentonite mixture, into an excavated trench. Excavation can be completed using a long-arm excavator or a clam shovel to achieve the required depth. Slurry is pumped into the hole during the course of excavation to keep the sidewalls from collapsing.

Effectiveness: Slurry walls would eliminate migration of contaminated groundwater horizontally and reduce mobility of the contaminant plume. Slurry wall barriers are effective in preventing additional groundwater contamination from migrating off-Site or for diverting uncontaminated groundwater around a contaminant source. Effectiveness is limited if a confining layer is not continuous below the source area. Use of this technology does not guarantee that further remediation may not be necessary and there is potential for the slurry wall to degrade or deteriorate over time. In addition, there is potential for contaminated groundwater to flow around the barrier. Mobilization of contaminated groundwater to the Rio Maunabo is highly undesirable.

Implementability: Slurry walls are constructible at this Site. Construction materials and services are readily available. Typical slurry wall applications reach installation depths of about 30 to 40 feet bgs, based upon practical limitations associated with excavator trenching. Slurry walls can be installed to depths of 100 feet bgs using a clam shovel at a higher unit cost. If a downgradient slurry wall is used to contain the plume, then additional technologies such as groundwater extraction would be necessary to control groundwater levels at the Site and reduce the likelihood of groundwater flowing around the wall.

Relative Cost: Slurry walls would involve moderate to high capital cost.

Conclusion: Slurry walls are not retained for further consideration in all three plumes due to their lack of effectiveness.

2.6.4.2 Sheet Pile Barriers

Sheet pile barriers are constructed by driving or vibrating sections of steel sheet piling into the ground. Each sheet pile section is interlocked at its edges, and the seams are often grouted to prevent leakage. Upon the completion of remedial activities, the sheet piles can be vibrated out of the ground, disassembled, and removed from the Site, provided that the sheeting and joints are still of good structural integrity at the time of removal. Otherwise, the sheets are cut off below the ground surface, and the walls continue to influence groundwater flow patterns on a localized scale.

Effectiveness: Sheet pile walls eliminate the horizontal migration of contaminated groundwater and reduce mobility of the plume. Installing sheet pile walls may enhance the vertical gradient, thus increasing the migration of contaminants into the bedrock aquifer, which is highly undesirable. If good, non-leaking, joints are installed, the sheet piling may be effective in preventing additional groundwater contamination from migrating off-Site or for diverting uncontaminated groundwater around a contaminant source. Effectiveness is limited if the joints are leaking. Use of this technology does not guarantee that further remediation in the future may not be necessary. Installing sheet pile walls in a plume with an uncertain source will reduce its effectiveness. In addition, there is potential for contaminated groundwater to flow around the wall.

Implementability: Sheet pile walls are implementable at the Site in terms of constructability. Sheet piles have been widely used in the heavy construction industry, particularly for groundwater control and slope stability. Construction materials and services are readily available. Typical sheet pile wall applications reach installation depths of approximately 80 feet bgs, based upon practical limitations associated with installation. Completely watertight joints are nearly impossible to install.

Relative Cost: Sheet pile walls would involve moderate to high capital cost, depending upon the depth to which the walls are installed.

Conclusion: Sheet pile walls are not retained for further consideration in all three plumes due to their lack of effectiveness.

2.6.5 Groundwater Extraction

Extraction technologies involve placing extraction wells or trenches to intercept the flow of contaminated groundwater and hydraulically prevent contaminants from migrating downgradient. The extracted groundwater is typically treated ex-situ and disposed of on-Site or off-Site. Representative process options are described below.

2.6.5.1 Extraction Wells

This process option involves the installation of groundwater extraction wells within areas of contamination to provide hydraulic control and capture of contaminant migration. Extraction wells are effective when combined with other treatment and discharge technologies. Potential scenarios for extraction wells include containment of source area groundwater, containment of the leading edge of the high concentration plume, or preventing contaminated groundwater from migrating off-Site.

Effectiveness: Groundwater extraction is effective in providing hydraulic control and removal at sites where the soil is highly permeable, the hydrogeology is well understood, and the pumping rate necessary to maintain hydraulic control is sustainable. Groundwater extraction reduces migration of contaminated groundwater and reduces concentrations of contaminants in groundwater over time. Groundwater extraction must be combined with treatment and disposal. Due to the moderate to high yield observed from wells at the Site, moderately permeable soil and the abundance of groundwater in an alluvial aquifer, extraction wells can be installed at the Site. However, the extraction wells would be competing with the public supply wells and would possibly decrease the production rate of Maunabo #1 and Maunabo #4, which would impact effectiveness.

Implementability: Installation of groundwater extraction wells is technically implementable. Necessary equipment and materials are readily available.

Relative Cost: Groundwater extraction would involve medium to high capital costs due to the depth of drilling required. Medium cost for O&M due to the prolonged period of operation generally required.

Conclusion: Extraction wells are not retained for further consideration in all three plumes due to their lack of effectiveness.

2.6.5.2 Extraction Trenches

This technology involves construction of a trench perpendicular to the direction of groundwater flow to intercept and prevent downgradient migration of a contaminant plume. A bio-polymer slurry is used to temporarily support the sidewalls of the trench, preventing collapse of the trench sidewalls. The trench is typically backfilled with material of higher permeability than the native aquifer (e.g., gravel) to create a zone of preferential flow, and perforated piping or well screens are typically installed in the trench to collect the intercepted groundwater. After the piping and backfill have been installed, an additive is pumped into the trench to break down the slurry to simple sugars and water, thus re-establishing hydraulic connection to the aquifer. Extracted groundwater is then treated as necessary to meet discharge requirements. Extraction trenches are generally used for contamination at shallow depth.

Effectiveness: Extraction trenches are effective in capturing groundwater to provide hydraulic control. However, an extraction trench is not typically installed at depths greater than 30 feet bgs due to trenching equipment limitations. The contaminant plume at the Site is deeper than 30 feet; therefore, extraction trenches would not be able to fully capture the contaminants.

Implementability: The equipment and materials are readily available. Extraction trenches are not easily implemented at deeper depths.

Relative Cost: Extraction trenches would involve high capital cost due to depth and medium O&M cost.

Conclusion: This technology is not retained for further evaluation in all three plumes due to its lack of effectiveness.

2.6.6 Ex-situ Treatment Technology

If air sparging is selected as a remediation option, an ex-situ treatment system may be required to remove contaminants from the extracted vapor before discharge. However, based on the low contaminant mass in the plumes at the Site, as discussed in Section 2.4.1, the need for an ex-situ treatment system will likely not be required. Several ex-situ treatment technologies were identified as potentially applicable at the Site.

2.6.6.1 Air Stripping

Air stripping is a physical mass transfer process that uses clean air to remove dissolved VOCs from extracted contaminated groundwater by increasing the surface area of the groundwater exposed to air. Commonly used systems include the counter-current packed column, multiple-chamber fine-bubble aeration systems, venturi systems, and low profile, sieve-tray air strippers. In a counter-current packed column, contaminated groundwater is sprayed through nozzles at the top of the column, flowing downward through packing materials. In a low profile, sieve-tray air stripper, contaminated groundwater flows across the surface of a series of perforated trays. In both systems, clean air is forced into the system by a (pressure or vacuum) blower in a direction opposite to groundwater flow (e.g., from the bottom, flowing upward). In a multiple-chamber, fine-bubble aeration system, contaminated groundwater flows through aeration tank chambers, and air is introduced at the bottom of each chamber via diffusers that form thousands of fine bubbles. As the fine air bubbles travel upward through the water, mass transfer occurs at the bubble/water interface. System efficiency increases with decreasing bubble diameters.

In general, the water stream exiting the air stripper can be discharged to surface water or groundwater. The water effluent may require a polishing step depending upon the influent water concentration and/or air to water ratio in the stripper. The vapor effluent may require treatment (e.g., carbon adsorption or thermal or catalytic oxidation) before discharge to the atmosphere.

Effectiveness: Air stripping would be effective in removing VOCs from water. The Henry's law constants for most of the Site contaminants indicate that these can be removed in the air stripper. Contaminants extracted from any of the contaminant plumes could be effectively treated. The process is susceptible to inorganic fouling and may require pretreatment steps such as pH adjustment or annual maintenance such as acid cleaning of the air stripper interior. Based on the low contaminant mass in the plumes, off-gas would likely not require treatment prior to discharge.

Implementability: Air stripping would be implementable. Vendors and equipment would be readily available to provide air strippers for groundwater VOC removal. It would need to be implemented with groundwater extraction and discharge technologies. Air stripping may require permits for discharge of VOCs to the atmosphere and/or off-gas treatment (i.e., vapor phase carbon) prior to discharge.

Relative Cost: Air stripping would have low capital and low O&M costs.

Conclusion: Air stripping is not retained for further evaluation for this Site since groundwater extraction is not retained.

2.6.6.2 Granular Activated Carbon (GAC) Adsorption

Extracted groundwater or off-gas can be pumped through vessel(s) containing GAC to which contaminants adsorb and are removed. When the concentration of contaminants in the effluent exceeds a pre-established value (breakthrough), the GAC is removed for regeneration or disposal.

Effectiveness: This process option would protect human receptors by reducing concentrations of contaminants in groundwater. Carbon adsorption would be effective in removing contaminants with moderate or high organic carbon partition coefficients (K_{oc}) from groundwater. The process is not effective in removing VC, which does not effectively adsorb to carbon. It is also not very effective in removing cis-1,2-DCE which has the tendency to break through quickly. It may be susceptible to biological and inorganic fouling. The technology is particularly effective for polishing water discharges from other remedial technologies to attain regulatory compliance.

Implementability: Activated carbon adsorption is implementable. The equipment and materials are readily available. Logistic and economic disadvantages arise from the need to transport and decontaminate spent carbon. Costs are high if it is used as the primary treatment on waste streams with high contaminant concentration levels. It would need to be combined with groundwater extraction and discharge technologies. O&M requirements include monitoring of influent and effluent streams, regeneration and replacement of carbon, and backwashing.

Relative Cost: This technology would involve medium capital and O&M costs.

Conclusion: GAC is not retained for further evaluation for this Site since groundwater extraction is not retained.

2.6.6.3 Ultraviolet/Oxidation

This process option is used when destruction of contaminants is preferred or when contaminants cannot be removed with GAC or air stripping. Extracted groundwater is transferred to a reactor where it is combined with ozone and/or hydrogen peroxide and irradiated with ultraviolet (UV) light. Organic contaminants are destroyed as a result of the synergistic action of the oxidant with UV light. The system may require off-gas treatment to destroy unreacted ozone and volatilized contaminants. This process option is used when destruction of contaminants is preferred or when contaminants cannot be removed with GAC or air stripping.

Effectiveness: UV/Oxidation would be an effective method to treat chlorinated VOC contaminants including VC, in groundwater extracted from the contaminant plumes of the Site. The aqueous stream must have good transmissivity; high turbidity causes interference. This technology would not be cost effective to treat contaminants extracted from a low concentration plume such as at the Site.

Implementability: This technology is implementable. Vendors and equipment for UV/oxidation are readily available. It can be implemented with groundwater extraction and discharge technologies. Minor administrative difficulties are anticipated for implementation of a UV oxidation system as it may require permit for discharge of unreacted ozone and volatilized VOCs. Alternatively, treatment of off-gas may be required.

Relative Cost: This technology would involve high capital and O&M costs. A UV/oxidation system is generally more costly than an equivalently-sized GAC unit. It would also require more electricity to operate.

Conclusion: UV/Oxidation is not retained for further evaluation due to high costs and electricity demand.

2.6.7 In-situ Treatment Technology

Several in-situ treatment technologies are identified and discussed below. In-situ technologies could generally achieve mass reduction within a shorter period of time compared to the groundwater extraction technologies, especially when the contaminant mass is located in lower permeability silty or clayey material.

2.6.7.1 In-situ Thermal Remediation

In-situ thermal remediation technology transfers heat into the subsurface, causing contaminants (especially VOCs) to vaporize or evaporate. Heat can be delivered by steam, conduction or by electrical resistivity heating (ERH).

ERH is an in-situ, three-phase electrical heating technology that applies electricity into the ground through electrodes. ERH raises the temperature of groundwater, increasing volatilization of contaminants that are subsequently removed in the vapor phase. As ERH dries the vadose-zone soil, it also creates a source of steam that strips contaminants from soils. Steam injection consists of direct injection of steam generated ex-situ into an aquifer through injection wells to vaporize volatile and semi-volatile contaminants. The vaporized compounds would then rise to the vadose zone where they are removed by vacuum extraction and treated. Steam enhanced extraction uses heater-vacuum wells to raise the soil temperature across the treatment volume, groundwater to boil and generating steam in-situ. This results in steam distillation of the contaminants, similar to steam flooding or ERH.

Effectiveness: In-situ thermal remediation has been successfully applied to remove contamination sources in silty or clayey soils. However, its effectiveness would be impacted if applied in plumes where the source is uncertain, such as at the Site. Residual heat would also be capable of stimulating accelerated biodegradation of remaining low-concentration contaminants.

In-situ thermal treatment is typically used for treating contaminant source areas rather than larger, less contaminated plumes such as at the Site. If too much unheated water enters the treatment zone from upgradient, it can create a significant heat sink, which decreases the efficiency of the technology. Effectiveness is highly dependent on the nature of the subsurface and heterogeneity of the soils.

Implementability: This method would be implementable by specialty vendors. The technology would require a significant, reliable source of electrical power in order to provide capacity to heat the groundwater especially to reach deeper depths. Puerto Rico Water Quality Standards (PRWQS) (March 2010) state that no heat may be added to the waters of Puerto Rico, which would cause the temperature of any site to exceed 90°F or 32.2 degrees Celsius (°C).

Relative Cost: This technology would involve high capital and O&M costs over a short period, approximately one or two years.

Conclusion: This process option is not retained due to high costs, effectiveness, and implementability concerns.

2.6.7.2 Air Sparging

Air sparging involves the injection of air or oxygen into the contaminated aquifer. Injected air strips organic contaminants in-situ and helps to flush the contaminants into the unsaturated zone. If the mass of VOCs is great enough, soil vapor extraction (SVE) may be implemented in conjunction with air sparging to remove the vapor-phase contamination from the vadose zone by vacuum extraction and, if required, vapor treatment to mitigate impacts to surface receptors. Based upon the relatively small contaminant mass in the plumes, an SVE system will likely not be required for this Site. The need for an SVE component is generally determined during a Site-specific pilot study. Oxygen in the air injected into contaminated groundwater can also enhance aerobic biodegradation of contaminants below and above the water table.

Effectiveness: Air sparging protects human receptors by reducing concentrations of contaminants in groundwater. This technology is effective for volatile, relatively insoluble organics. Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors. Depending on the mass of sparged vapors, air sparging could increase exposure to surface receptors if not implemented in conjunction with SVE. The effectiveness of this technology largely depends upon distribution of contaminants, heterogeneity of the aquifer, preferential flow paths and the ability to actively direct contact of air with contaminated groundwater.

Implementability: This method is implementable. The system would likely not require off-gas treatment.

Relative Cost: This technology would involve moderate capital and O&M costs.

Conclusion: This process option will be retained for the cis-1,2-DCE since the plume is at a relatively shallow depth relative to the vadose zone. It is not retained for the 1,1-DCE or PCE plumes due to their depth in the aquifer and the low total mass in each plume.

2.6.7.3 In-situ Chemical Reduction

In-situ chemical reduction is a process using a reductant to react with contaminants in groundwater to reduce the contaminants to non-hazardous compounds. The most widely used reductant for reducing chlorinated hydrocarbons is zero-valent iron (ZVI). Other zero-valent metals have also been used alone or in combination with ZVI to treat contaminants, such as zinc and bimetallic reductants (nickel/iron, copper/iron).

ZVI has been applied in several ways to remediate contaminants: in a bio- barrier type application; in nano-scale through injection; and in micro-scale through injection. Recently, ZVI has also been combined with organic carbon amendments, for example, emulsified zero-valent iron (EZVI) is a proprietary product developed by National Aeronautics and Space Administration (NASA) containing emulsified oil coated ZVI; and EHC®, a proprietary product developed by Adventus containing ZVI and controlled-release carbon in a solid form.

Effectiveness: A combination of ZVI with an organic substrate to stimulate anaerobic biodegradation would have the potential to treat Site contaminants. This process option would protect human receptors by reducing concentrations of contaminants in groundwater. Achieving uniform delivery of the reductant and adequate contact of reductant with contaminants would be critical for effective treatment, which rely on proper implementation of this technology. The reductant can be delivered using injection wells.

Implementability: This method is implementable. The equipment for in-situ injection would be readily available. Liquid injection would be a method for delivering the reductant in-situ. In-situ chemical reduction would be implemented using EHC® for the contaminant plume. Treatability testing and pilot-scale testing will be required. In-situ chemical reduction may result in secondary water quality changes like increase in concentrations of iron and manganese in the groundwater. Potential impacts to the public water supply system will need to be evaluated prior to implementation.

Cost: This technology would involve medium to high capital cost and low O&M cost.

Conclusion: This process option is retained for further evaluation in the cis-1,2-DCE plume assuming that a chemical reductant may be used in combination with an organic carbon amendment to stimulate in-situ bioremediation. It is not retained for the 1,1-DCE or PCE plumes due to the low total mass in each plume.

2.6.7.4 In-situ Chemical Oxidation

In-situ chemical oxidation (ISCO) is an aggressive treatment approach that involves the injection of chemical oxidants into the subsurface to destroy organic contaminants in groundwater. The commonly used oxidants include ozone, Fenton's Reagent, permanganate, activated persulfate, catalyzed percarbonate, etc. Complete oxidation of contaminants results in their breakdown into less toxic compounds such as carbon dioxide, water, and chloride. A number of factors affect the performance of this technology, including oxidant delivery to the subsurface, oxidant type, dose of oxidant, contaminant type and concentration, and non-contaminant oxidant demand.

There are fundamental issues with the delivery of radical based oxidants. The radicals have extremely short lives and need to be generated in the subsurface where the contaminants are located. Therefore, a repeat application of oxidant is generally required.

Effectiveness: ISCO would be capable of reducing contaminant mass in high concentration plumes and thereby protect human receptors. This technology is not effective for application in low concentration plumes such as at the Site. ISCO can achieve effective contaminant destruction if adequate contact between reagents and contaminants occurs (i.e., adequate quantity of oxidant distributed and in contact with contaminants long enough for oxidation to occur). Another limitation on effectiveness is the limited lifespan of the oxidizing agent. ISCO can interfere with anaerobic degradation processes.

Implementability: This process option is relatively easy to implement using readily available equipment; however, a treatability study and pilot scale testing may be required. Chemical delivery can be challenging in heterogeneous formations. Since the groundwater at the Site is a source of potable water, administrative difficulties can be anticipated, including meeting substantive requirements of applicable injection permits for reagents. The width, depth, and length of the low concentration plume combined with the low life span of oxidant would likely require a high density of injection points, a large quantity of oxidant, and multiple injection rounds.

Relative Cost: ISCO would involve high capital and low O&M costs.

Conclusion: ISCO is not retained for further evaluation in any of the three plumes due to administrative difficulties, low concentrations, no identified source, and uncertainty in effectiveness. Due to the lower concentrations involved, ISCO would not be cost effective for the contaminant plumes when compared to in-situ chemical reduction or in-situ bioremediation.

2.6.7.5 In-situ Bioremediation

In-situ bioremediation provides protection of human health through bioremediation of VOC mass from groundwater by injection of amendments to stimulate the anaerobic degradation process. Bioremediation amendments include both amendments that primarily stimulate biotic reactions, such as source of electron donors (e.g., whey, lactate, emulsified oil) and those that also stimulate biotic/abiotic reactions such as ZVI alone and in combination with biotic amendments (e.g., commercially available EHC® by Adventus Americas). Monitoring would be performed to ensure that these controls are protective of human health.

The predominant mechanism for biological degradation of chlorinated aliphatic hydrocarbons (CAHs), such as PCE, is reductive dechlorination. The primary degradation pathway for PCE is microbially mediated reductive dechlorination, whereby its chlorine atoms are successively stripped off to form less chlorinated compounds. Reductive dechlorination is a sequential process that results in the generation of by products such as TCE, cis-1,2-DCE, VC and ultimately can lead to complete detoxification (e.g., ethene). The process is strictly anaerobic and can occur under sulfate-reducing redox conditions, but is most efficient (i.e., results in ethene generation) under methanogenic redox conditions. A factor limiting the biological transformation of CAHs is typically the lack of sufficient electron donor to drive the dechlorination process, or in some cases, the lack of bacteria capable of carrying out the complete transformation process to ethene (*dehalococcoides* [DHC] species is the only genus of bacteria demonstrated to reduce cis-1,2-DCE to VC and ethene).

In order to bolster biotic transformation processes, amendments that also contain reactants that abiotically transform contaminants (i.e., reductive iron such as ZVI) are also considered. Reductive iron stimulates reductive beta-elimination where cis-1,2-DCE is converted to chloroacetylene, acetylene, ethene, and then ethane. Abiotic degradation of TCE or 1,1,1-TCA results in the formation of 1,1-DCE. The benefit of the abiotic reactions is that there is little/no accumulation of degradation by-products. In addition, combining reductive iron within biological amendments creates much more reduced conditions than biotic amendments alone, which also makes biological reactions much more favorable and efficient.

Effectiveness: In-situ bioremediation protects human receptors by eliminating exposure to contaminants and reducing concentrations of contaminants in groundwater. Overall natural geochemistry of the cis-1,2-DCE plume has been found to be favorable for reductive dechlorination. Introduction of a suitable electron donor would create reducing conditions across the entire area, thereby enhancing reductive dechlorination in the cis-1,2-DCE plume. VC is more commonly remediated using aerobic mechanisms than anaerobic.

Implementability: In-situ bioremediation is relatively easy to implement using readily available equipment. Remedial delivery can be challenging in heterogeneous formations. Limitations include: delivery method for nutrients, presence of nutrients in the subsurface, carbon source, and type of microorganisms present in subsurface. Microcosm study and pilot-scale testing would be required.

Relative Cost: This technology would involve medium capital cost and low O&M cost.

Conclusion: In-situ bioremediation is retained for further evaluation in the cis-1,2-DCE plume. It is not retained for the 1,1-DCE or PCE plumes due to the low total mass in each plume.

2.6.8 Discharge

Once groundwater has been treated, it will be discharged on-Site or off-Site. Potential on-Site and off-Site discharge options for groundwater are evaluated below.

2.6.8.1 On-Site Injection

This on-Site discharge technology involves injecting treated groundwater to the subsurface using a series of wells. Injection requires that the groundwater be treated to meet applicable groundwater standards prior to disposal to the subsurface.

Effectiveness: The effectiveness of this option would rely on proper injection well design and construction, including adequate pipe sizing, proper placement of the wells, and reliable construction materials.

Implementability: Discharge of treated effluent to a series of injection wells is easily implementable, using available construction resources and equipment. Some implementability problems could arise during long-term operation of injection wells, such as clogging of screen packs with precipitates or microbial fouling, particularly in high iron conditions. These problems could be overcome by proper removal of suspended solids and excess iron from the treated water, periodic chlorination of the injected water, and redevelopment and cycling on/off of wells. Discharge of treated effluent may be required to meet substantive requirements of EPA UIC permit and the PRWQS (March 2010).

Relative Cost: This technology would involve medium capital and medium O&M costs if well rehabilitation needs to be performed periodically.

Conclusion: Injection is not retained for further evaluation at the Site since groundwater extraction is not retained.

2.6.8.2 Surface Water Discharge

Treated groundwater can be discharged to a surface water body such as a nearby pond or stream. Disposal to an off-Site surface water body would require that the extracted groundwater be treated to meet applicable surface water discharge standards.

Effectiveness: Discharge to an off-Site surface water body would be an effective method for disposal of treated groundwater, depending on the distance from the treatment system to the stream. Discharge to a surface water body such as the Rio Maunabo would be an effective method for disposal of treated groundwater.

Implementability: Discharge to a surface water body is easily implementable using available construction resources. This process option would be required to meet substantive requirements of NPDES permit and PRWQS (March 2010) for discharge.

Relative Cost: This technology would involve low capital and O&M costs.

Conclusion: Surface water body discharge is not retained for further evaluation at the Site since groundwater extraction is not retained.

2.6.8.3 Discharge to Publicly Owned Treatment Works

This process option would involve off-Site discharge of treated groundwater or treatment waste residuals to a publicly owned treatment works (POTW) facility via a sanitary sewer. PRASA's wastewater treatment facility is located close to Maunabo #1.

Effectiveness: This would an effective option if there are sanitary sewers in the vicinity of the Site and the treated water meets the wastewater treatment facility requirements and intake capacity.

Implementability: Discharge to sanitary sewers would be implementable using available construction resources if sanitary sewer system is present near the Site. Discharged water may require pre-treatment to meet the facility acceptance requirements. The discharge technology must be combined with extraction and ex-situ treatment.

Relative Cost: Discharge to POTW would involve low capital and medium O&M costs.

Conclusion: Sanitary sewer discharge is not retained for further evaluation in any of the three plumes since groundwater extraction is not retained.

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Section 3

Development and Screening of Remedial Action Alternatives

3.1 Overview

In this section, remedial action alternatives (herein referred to as remedial alternatives) are assembled by combining the retained remedial technologies and process options presented in Section 2 for each contaminated media. Remedial alternatives are developed from either stand-alone process options or combinations of the retained process options.

The remedial alternatives for the Site span a range of categories defined by the NCP as follows:

- No action alternative
- Alternatives that address the principal threats but involve little or no treatment include those where protection would be by prevention or control of exposure through actions such as containment, engineered controls, and/or institutional controls
- Alternatives that, as their principal element, employ treatment that reduces the toxicity, mobility, or volume of the contaminants, that may be innovative
- Alternatives that remove or destroy contaminants to the maximum extent, eliminating or minimizing long-term management

The technologies and process options retained for groundwater as either primary, secondary or contingency components include the following:

- No Action
- Monitoring
- Institutional Controls
  - Land Use Controls
  - Groundwater Use Controls
- Community Awareness
- Monitored Natural Attenuation
- In situ treatment
  - Biodegradation

  - Air sparge/Soil Vapor Extraction (AS/SVE)
  - Chemical Reduction
- Physical Ex-situ Treatment
  - Air Stripping

In some cases, an alternative description may include a general technology for a portion of the remedy (e.g., in-situ treatment for contaminated source zone areas). This generalized description is necessary so that the Record of Decision (ROD) may allow Site-specific bench-scale or pilot testing of several technology process options (e.g., in-situ treatment). This flexibility will allow the most successful technology to be selected and designed for full-scale implementation. In these cases, a representative remedial technology process option is selected during the FS to simplify the analysis and comparison of alternatives, while it is understood that the alternative will allow flexibility in the final design.

3.2 Assumptions Affecting Development of Remedial Alternatives

Several fundamental assumptions affect the development of remedial alternatives evaluated in this FS (other than a "no action alternative"). These assumptions are driven by requirements of the RAOs and Site limitations and constraints that cannot be overcome by using one or more remedial technology/process options as described in Section 2. These fundamental assumptions were taken into consideration during development of remedial alternatives for this FS and include the items listed in Exhibit 3-1. Note that changes to Site conditions or the current understanding of Site conditions may affect these current fundamental assumptions, which in turn, may impact the remedial alternatives developed for the Site.

Exhibit 3-1. Assumptions Affecting Development of Remedial Alternatives

Fundamental Assumption	Rationale
PRASA will continue to operate Maunabo #1 and #4 as water supply wells	Maunabo #1 and #4 are important sources of drinking water for PRASA and will remain in operation.
Institutional Controls and Monitoring are Essential GRA Components of all Alternatives	Contaminated groundwater has been identified during previous monitoring and Site investigations. After implementing a remedial alternative, there is the possibility that unidentified portion(s) of the Site outside the remediated areas contain back-diffused contaminants in low-permeability zones within the aquifer, sorbed contaminants on soils and/or dissolved contaminants in groundwater that could pose a risk to human health. Thus, it is assumed that institutional controls and

Fundamental Assumption	Rationale
	monitoring are essential GRA components of all remedial alternatives (except the "no action" alternative required by the NCP) and will be implemented while contaminant levels remain at concentrations that could pose a risk to human health.
Inclusion of Treatability Studies within Alternatives	Some alternatives may require the completion of Site-specific treatability studies to confirm that selected technologies will adequately address contamination.
Monitoring Used to Determine Protectiveness and Need for Additional Remedial Measures	It is assumed that monitoring (consisting of soil, groundwater, and/or air sampling) will be performed to help evaluate protectiveness of the remedy after implementation and the need for any future additional remedial measures to address remaining contamination. These additional remedial measures are excluded from the screening and evaluation of remedial alternatives since they would be a contingency measure enacted after consideration and evaluation of the monitoring data. .
30-Year Period of Evaluation for Groundwater Alternatives	Remedial alternatives that require an indefinite duration of O&M due to institutional controls and monitoring will be evaluated for a default 30 year period.

3.3 Description of Remedial Action Alternatives

Remedial alternatives were assembled by combining the retained remedial technologies and process options for each contaminated media. Table 2-5 provides a comprehensive list of the remedial technologies/process options that are used for each remedial alternative. The fundamental Site assumptions and factors described in Section 3.2 were also considered during development of the remedial alternatives.

The remedial alternatives to address groundwater contamination in each of the three plumes are presented in Table 3-1 and are summarized below.

- Alternative 1: No Action
- Alternative 2: MNA (all three plumes)
- Alternative 3: AS/SVE (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)
- Alternative 4: In-situ Bioremediation (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

3.3.1 Common Elements

There are several common elements which it is assumed will be included as part of each remedial alternative. With the exception of five year Site reviews, the common elements listed below do not apply to the No Action alternatives. The common elements include the items below.

Monitoring – Periodic monitoring of Site groundwater can be implemented when contaminants remain above levels that allow for unrestricted use and unlimited exposure. The monitoring program should continue until concentrations have stabilized or met remedial goals.

Institutional controls –Institutional controls should restrict the future use of the Site and groundwater, and should require precautions to be taken to protect human health in the event remedial measures are disturbed.

Five-year Site reviews – Per CERCLA, alternatives resulting in contaminants remaining above levels that allow for unrestricted use and unlimited exposure, require that the Site be reviewed at least once every five years. If justified by the review, additional remedial actions may be implemented to remove, treat, or contain the contamination. The Site review would include a Site-wide visual inspection and a report prepared by EPA.

3.3.2 Detailed Description of Groundwater Remedial Alternatives

3.3.2.1 Alternative 1: No Action

A "no action" alternative is required by the NCP to provide an environmental baseline against which impacts of the various remedial alternatives can be compared. Under this alternative, no action would be taken to remedy the contaminated groundwater or to monitor contaminant concentrations to address the associated risks to human health or the environment. Because this alternative would result in contaminants remaining on-Site above levels that allow for unrestricted use and unlimited exposure, CERCLA requires that the Site be reviewed at least once every five years. If justified by the review, remedial actions may be implemented to remove or treat the wastes.

3.3.2.2 Alternative 2: MNA (all three plumes)

MNA is not a specific technology, but relies upon physical and biological processes (unassisted by human intervention) to effectively reduce contaminant concentrations such that remedial objectives in the contaminant plume are achieved in a reasonable time frame. Given the low total mass of contaminants in each of the three plumes, MNA is an important alternative to consider.

The most desirable natural attenuation process is biodegradation; dilution and dispersion will cause an effective reduction in concentrations, but are less desirable because contaminant mass is not destroyed. Biodegradation to non-toxic byproducts is expected in the 1,1-DCE plume as it travels downgradient to aerobic zones. Evidence of biodegradation gathered during the RI was inconclusive for the cis-1,2-DCE plume; but for the RAOs to be met in this plume, it is critical that biodegradation occur inside the existing plume footprint. During the design phase, further investigations to prove active biodegradation in the cis-1,2-DCE plume are suggested, such as studies of microbial abundance and genetics, and compound-specific isotope analysis. In the PCE plume, non-destructive mechanisms are expected to reduce concentrations below PRGs in groundwater within a reasonable time frame.

Under this alternative, no active remedial action would be taken to remediate the three groundwater plumes unless, after a specified period of monitoring, groundwater contaminant levels are not decreasing as a result of natural processes. If monitoring indicates that levels are not decreasing sufficiently, a contingency plan would need to be implemented. If contaminant concentrations appear to reach steady state at levels above the PRGs, an active remedy such as those technologies proposed in Alternatives 3 and 4 may be necessary to achieve PRGs. The active remedy will be defined in the ROD, or if necessary, in a subsequent ROD amendment or Explanation of Significant Difference (ESD).

Performance monitoring is a critical component of this remediation approach because monitoring is needed to ensure that the remedy is protective and that natural processes are reducing contamination levels as expected. It is recommended that groundwater modeling be performed and additional monitoring wells be installed to evaluate MNA performance.

3.3.2.3 Alternative 3: AS/SVE (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

Under this alternative, air sparging would be used to strip VOCs from the groundwater in the cis-1,2-DCE plume and reduce concentrations to below the PRGs. MNA is proposed for the other two plumes, since they have low total mass and the hydrogeology is such that the supply wells are not facing an imminent threat of concentrations above MCLs.

For costing purposes, a combination of two different sparge configurations in the cis-1,2-DCE plume is considered that take advantage of pumping in Maunabo #1 and the permeability of the aquifer. Groundwater flow velocity increases exponentially as distance to the well decreases. A grid of sparge points would be installed in areas of slow moving groundwater—relatively far from the pumping well—near MW-B, and a row of sparge points (a sparge curtain) would be installed closer to the well in the faster moving groundwater. Each sparge point is assumed to have a 10-foot radius of influence. This configuration is considered to be cost- and performance-optimized compared to a configuration consisting solely of a grid of sparge points across the entire plume. A conceptual design of the sparge configuration is presented in Figure 3-1.

An SVE system could be implemented in the vadose zone to collect the VOCs stripped from groundwater by the sparge system. It should be noted that since concentrations in groundwater are low, the mass collected by the SVE system would be very low and potentially below detection limits in the system effluent if sampled. Furthermore, biodegradation in the aerobic conditions created by the sparge system and also in the vadose zone would further decrease the mass of cis-1,2-DCE and VC to be captured by the SVE. There would likely be no need to treat the vapor prior to release to the atmosphere because discharge rates would be lower than Puerto Rico standards.

The SVE system is costed in this FS without vapor treatment; however, the need for an SVE and for vapor treatment should be evaluated thoroughly during remedial design.

If monitoring in the PCE and 1,1-DCE plumes indicates that levels are not decreasing sufficiently, a contingency plan would need to be implemented. If contaminant concentrations appear to reach steady state at levels above the PRGs, an active remedy (such as AS/SVE or the technology discussed in Alternative 4, in-situ bioremediation) may be necessary to achieve PRGs. The active remedy will be defined in the ROD, or if necessary, in a subsequent ROD amendment or ESD.

Monitoring is a critical component of this remediation approach because it is needed to ensure that the remedy is protective and that air sparge and natural processes are reducing contamination levels as expected. It is recommended that additional monitoring wells be installed to evaluate performance.

3.3.2.4 Alternative 4: In-situ Bioremediation (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

Under this alternative, in-situ bioremediation would be implemented within the 70 µg/L contour in the cis-1,2-DCE plume, with institutional/engineering controls for protection of human health. A long-term monitoring program would be implemented to ensure that further migration of contaminants of concern (COCs) is not occurring. Results from the long-term monitoring program would support the decision making on implementation of institutional/engineering controls. It is recommended that additional monitoring wells be installed to facilitate monitoring.

For the purposes of evaluation, comparison, and costing in the FS, EHC® is used as the representative amendment. A microcosm study would be conducted for the plume. The microcosm study would evaluate the effectiveness of EHC® and other amendments such as lactate/whey, in order to select the most cost-effective amendment(s) for this Site. A pilot study may need to be conducted prior to the remedial design to obtain Site-specific design parameters for the full scale implementation of bioremediation. A pre-design investigation would be conducted to further delineate the vertical and lateral extent of the treatment zone in the plume.

For this FS, in-situ bioremediation of the cis-1,2-DCE plume would be conducted by injecting the EHC® amendment in the form of bio-barriers over the target treatment area, delineated during the pre-design investigation. Each bio-barrier would consist of a series of injection points that would inject the EHC® amendment into the plume. The amendment can be injected using direct push technology or permanent injection points. Direct push technology would be considered for delivery of the amendment and evaluated further in Section 4 of this FS. Based upon the low concentrations of the contaminants, only one round of amendment injection may be necessary. The reducing conditions created by the amendment injection would potentially enhance natural attenuation of remaining low concentration contaminants in the vicinity of treatment.

In the PCE and 1,1-DCE plumes, MNA would be relied upon to ensure that the groundwater remediation RAO is met, as described in Alternative 2. Institutional controls such as deed restrictions and well drilling restrictions would be implemented to eliminate the exposure pathways of contaminated groundwater to receptors. Long-term monitoring would involve annual groundwater sampling and periodic reviews to monitor and evaluate contaminant migration and concentration changes in the aquifer.

3.4 Selection of Alternatives for Further Evaluation

Since only a limited number of remedial alternatives were developed, all alternatives will be carried forward for detailed analysis. Screening of remedial alternatives will not be performed.

Section 4

Detailed Analysis of Remedial Action Alternatives

As indicated in Section 3.5, groundwater alternatives were carried forward for evaluation against the criteria described below.

4.1 Evaluation Criteria

EPA's nine evaluation criteria address statutory requirements and considerations for remedial actions in accordance with the NCP and additional technical and policy considerations that have proven to be important for selecting among remedial alternatives (EPA 1988). The following subsections describe the eight evaluation criteria used in the detailed analysis of remedial alternatives.

4.1.1 Overall Protection of Human Health and the Environment

Each alternative is assessed to determine whether it can provide adequate protection of human health and the environment (short- and long-term) from unacceptable risks posed by hazardous substances, pollutants, or contaminants present at the Site. Evaluation of this criterion focuses on how Site risks are eliminated, reduced, or controlled through treatment, engineered controls, or institutional controls and whether an alternative poses any unacceptable cross-media impacts.

4.1.2 Compliance with ARARs

Section 121(d) of CERCLA, 42 USC § 9621(d), the NCP, 40 CFR Part 300 (1990), and guidance and policy issued by EPA require that remedial actions under CERCLA comply with substantive provisions of ARARs from the State (herein, the Commonwealth) and Federal environmental laws and Commonwealth facility siting laws during and at the completion of the remedial action.

4.1.2.1 Identification of ARARs

The definition and identification of ARARs have been described and discussed in detail in Section 2.3. Three classifications of requirements are defined by EPA in the ARAR determination process. ARARs are defined as chemical-, location-, or action-specific. An ARAR can be one or a combination of all three types of ARARs.

The Federal and Commonwealth of Puerto Rico ARARs for the Maunabo Site are listed in Tables 2-1 through 2-3. Each alternative is evaluated to determine how chemical-, location-, and action-specific ARARs identified in the ROD will be met.

4.1.2.2 Waivers of Specific ARARs

Superfund specifies situations under which the ARARs may be waived (40 CFR 300.430: Remedial Investigation/Feasibility Study (f) Selection of Remedy). The situations eligible for waivers are shown in Exhibit 4-1.

Exhibit 4-1 Eligibility of Waivers

Waiver	Description
Interim Measures	The remedial action selected is only part of a total remedial action that will attain such level or standard of control when completed. (CERCLA §121(d)(4)(A).)
Greater Risk to Health and the Environment	Compliance with such requirement at the facility will result in greater risk to human health and the environment than alternative options. (CERCLA §121(d)(4)(B).)
Technical Impracticability	Compliance with such requirement is technically impracticable from an engineering perspective. (CERCLA §121(d)(4)(C).)
Equivalent Standard of Performance	The remedial action selected will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, criteria, or limitation through use of another method or approach. (CERCLA §121(d)(4)(D).)
Inconsistent Application of Local Requirements	With respect to a local standard, requirement, criteria, or limitation, the state (herein, the commonwealth) has not consistently applied (or demonstrated the intention to consistently apply) the standard, requirement, criteria, or limitation in similar circumstances at other remedial actions. (CERCLA §121(d)(4)(E).)
Fund Balancing	In the case of a remedial action to be undertaken solely under section 104 using the fund, selection of a remedial action that attains such level or standard of control will not provide a balance between the need for protection of public health and welfare and the environment at the facility under consideration, and the availability of amounts from the fund to respond to other Sites which present or may present a threat to public health or welfare or the environment, taking into consideration the relative immediacy of such threats. (CERCLA §121(d)(4)(F).)

Where remedial actions are selected that do not attain ARARs, the lead agency must publish an explanation in terms of these waivers. It should be noted that the "fund balancing waiver" only applies to Superfund-financed remedial actions.

ARARs apply to actions or conditions located on-Site and off-Site. On-Site actions implemented under CERCLA are exempt from administrative requirements of federal and local regulations, such as permits, as long as the substantive requirements of the ARARs are met. Off-Site actions are subject to the full requirements of the applicable standards or regulations, including all administrative and procedural requirements.

Based on the CERCLA statutory requirements, the remedial actions developed in the FS will be analyzed for compliance with federal and commonwealth environmental regulations. This process involves the initial identification of potential requirements, the evaluation of the potential requirements for applicability or relevance and appropriateness, and finally a determination of the ability of the remedial alternatives to achieve the ARARs. This FS provides a preliminary discussion of the regulations that are applicable or relevant and appropriate to the remediation of the contaminated media at the Site. Both Federal and Commonwealth environmental regulations and public health requirements are evaluated. In addition, this FS identifies Federal and Commonwealth criteria, advisories, and guidance as TBCs.

4.1.3 Long-Term Effectiveness and Permanence

Long-term effectiveness evaluates the likelihood that the remedy will be successful and the permanence that it affords. Factors to be considered, as appropriate, are discussed below.

- Magnitude of residual risk remaining from untreated waste or treatment residuals remaining at the conclusion of the remedial activities. The characteristics of the residuals are considered to the degree that they remain hazardous, taking into account their T/M/V and propensity to bioaccumulate.

- Adequacy and reliability of controls that are used to manage treatment residuals and untreated waste remaining at the Site. This factor includes an assessment of containment systems and institutional controls to determine if they are sufficient to ensure that any exposure to human and ecological receptors is within protective levels. This factor also addresses the long-term reliability of management controls for providing continued protection from residuals, the assessment of the potential need to replace technical components of the alternative, and the potential exposure pathways and risks posed should the remedial action need replacement.

4.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Each alternative is assessed for the degree to which it employs a technology to permanently and significantly reduce T/M/V including how treatment is used to address the principal threats posed by the Site. Factors to be considered, as appropriate, include the following:

- The treatment processes the alternatives employ, and materials they will treat

- The amount of hazardous substances, pollutants, or contaminants that will be destroyed or treated, including how the principal threat(s) will be addressed

- The degree of expected reduction in T/M/V of the waste due to treatment

- The degree to which the treatment is irreversible

- The type and quantity of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate such hazardous substances and their constituents
- Whether the alternative would satisfy the statutory preference for treatment as a principal element of the remedial action

4.1.5 Short-Term Effectiveness

This criterion reviews the effects of each alternative during the construction and implementation phase of the remedial action until remedial response objectives are met. The short-term impacts of each alternative are assessed, considering the following factors, as appropriate:

- Short-term risks that might be posed to the community during implementation of an alternative
- Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures
- Potential adverse environmental impacts resulting from construction and implementation of an alternative and the reliability of the available mitigation measures during implementation in preventing or reducing the potential impacts
- Time until protection is achieved for either the entire Site or individual elements associated with specific site areas or threats.

4.1.6 Implementability

The technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation is evaluated under this criterion. The ease or difficulty of implementing each alternative is assessed by considering the following factors detailed in Exhibit 4-2.

Exhibit 4-2 Implementability Factors to be Considered during Alternative Evaluation

Criterion	Factors to be Considered
Technical Feasibility	Technical difficulties and unknowns associated with the construction and operation of a technology Reliability of the technology, focusing on technical problems that will lead to schedule delays Ease of undertaking additional remedial actions, including what, if any, future remedial actions would be needed and the difficulty to implement additional remedial actions Ability to monitor the effectiveness of the remedy, including an evaluation of risks of exposure should monitoring be insufficient to detect a system failure
Administrative Feasibility	Activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-Site actions)
Availability of Services and Materials	Availability of adequate off-Site treatment, storage capacity, and disposal capacity and services Availability of necessary equipment and specialists and provisions to ensure any necessary additional resources Availability of services and materials plus the potential for obtaining competitive bids, which is particularly important for innovative technologies Availability of prospective technologies

4.1.7 Cost

Detailed cost estimates for each alternative were developed for the Final FS according to *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000a). Detailed cost estimates for this alternative are included in Appendix A and include the following:

- Capital costs
- Annual O&M costs
- Periodic costs
- Present value of capital and annual O&M costs

4.1.8 Commonwealth (Support Agency) Acceptance

Commonwealth (support agency) acceptance is a modifying criterion under the NCP. Assessment of commonwealth acceptance will not be completed until comments on the Final FS Report are submitted to EPA. Thus, Commonwealth acceptance is not considered in the detailed analysis of alternatives presented in the FS.

4.1.9 Community Acceptance

Community acceptance is also a modifying criterion under the NCP. Assessment of community acceptance will include responses to questions that any interested person in the community may have regarding any component of the remedial alternatives presented in the Final FS Report. This assessment will be completed after EPA receives public comments on the Proposed Plan during the public commenting period. Thus, community acceptance is not considered in the detailed analysis of alternatives presented in the FS.

4.2 Secondary Assumptions Affecting Detailed Analysis of Remedial Alternatives

Fundamental assumptions that were used to develop remedial alternatives for the Site were presented in Section 3. In addition to those fundamental development-related assumptions, there are several categories of secondary assumptions that potentially affect implementation of the alternatives. The basis for the detailed analysis of alternatives against EPA threshold and balancing criteria presented in Section 4.3 is that these secondary assumptions will generally be met, however, a consideration of what the impact might be if they are not met also should factor into the evaluation and ultimate selection of an alternative. These assumptions are driven mainly by Site limitations and constraints and are common to most if not all of the alternatives developed for the Site. Exhibit 4-3 presents the assumptions and potential impact on remedy implementation if the assumption is not met.

Exhibit 4-3 Secondary Assumptions Affecting Refinement and Detailed Analysis of Remedial Alternatives

Secondary Assumption Category	Secondary Assumption Description	Rationale	Impact if Assumption Not Met
Land Use Control Assumptions	Land Use Controls for Privately Owned Parcels are Primarily Institutional Controls and Community Awareness Activities	Establishment of access control such as posted warnings may be difficult on privately owned parcels that are occupied and are actively used. It is also uncertain whether legal authority exists to install access controls extensively on privately owned parcels. However, the legal authority exists to implement certain types of institutional controls (for instance informational devices) as well as community awareness activities.	If institutional controls cannot be used to effectively control access, engineering controls may be required which may cause minor impact to remedial costs and schedule (relative to other components).

Secondary Assumption Category	Secondary Assumption Description	Rationale	Impact if Assumption Not Met
		Thus, land use controls for privately owned parcels are assumed to be primarily institutional controls and community awareness activities.	
Treatment Zone	Dimensions of Treatment Zone are approximate	The estimated lateral extent of the impacted treatment zones described in Sections 2.1.1 and 2.1.2 and shown in Figure 2-1 were established with data available to date and used to develop the remedial alternatives.	Any new data that shows an increase in the size of the treatment zone to be addressed may lead to a lengthening of the project schedule and an increase in project costs.
	Extent of influence of proposed alternatives involving ex-situ and in-situ treatment	The proposed alternatives that involve in-situ and ex-situ treatment attempt to treat a certain zone around each extraction well or injection well. The actual zone of influence of treatment will not be known until detailed pilot studies are completed.	Results from pilot studies may likely indicate that there will be zones between the wells that are not influenced by the proposed remedy.
Site Setting and Conditions	Impact on Remedy Implementation	Location of existing buildings, Site features and local subsurface conditions may preclude or limit the use of certain technologies.	Limitations due to Site setting and/or local hydrogeological properties may require the elimination or re-design of remedy components causing delay to the project schedule and an increase in costs.
Community and Stakeholders	Community and stakeholders acceptance	It is assumed that the community and stakeholders will approve remedial activities proposed for the Site.	Project schedule will be delayed if proposed activities are not approved and must be replaced or the approval process is slow.

Secondary Assumption Category	Secondary Assumption Description	Rationale	Impact if Assumption Not Met
Technology Vendors	Vendor/Contractor Availability and Experience	Qualified, experienced vendors are available for each of the technologies that will be employed to remediate the Site.	The project schedule would be delayed as additional time would be required to find and procure qualified vendors and contractors. Project costs may increase significantly if work completed by a vendor/contractor is substandard and has to be re-done.
Pilot Studies	Technology applicability	Each alternative includes the completion of Site-specific pilot studies to confirm that selected technologies will adequately address contamination.	The project schedule and cost impact if pilot studies indicate that selected technologies do not sufficiently address contamination. The selected remedy may need to be re-designed or a contingency remedy may need to be employed.
Energy Costs	Unit energy costs (electricity, fuel, etc.) needed to complete remedial activities	No rapid, substantial increase in energy costs is anticipated as project progresses from FS to remedy implementation.	Rapid, sustained increases in energy costs will increase overall project costs. Energy-intensive alternatives will be most affected and may require reconsideration if energy cost increases are substantial.
Institutional Controls and Monitoring	Institutional Controls and Monitoring	It is assumed that institutional controls and monitoring are an integral part of all alternatives and will be implemented to the degree required for a particular alternative.	If institutional controls are not employed, remedial alternatives may not be fully protective of human health during the time needed to implement and complete the remedial alternative.

4.3 Detailed Analysis of Remedial Alternatives

This section provides detailed descriptions and analysis of the remedial alternatives developed in Section 3 for the Site. Table 4-1 provides an initial evaluation of the remedial alternatives against EPA's evaluation criteria. In addition, Alternatives 2, 3, and 4 include the work necessary to perform long-term monitoring of all three plumes at the Site. The remedial alternatives retained for detailed analysis include:

Alternative 1 – No Action

Alternative 2 – MNA (all three plumes)

Alternative 3 – AS/SVE (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

Alternative 4 – In-situ Bioremediation (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

4.3.1 Common Elements

4.3.1.1 Institutional Controls

Institutional controls are implemented as part of all the proposed alternatives (other than the No Action alternative). Implementation of institutional controls will be performed to control, limit, and monitor activities and conditions at the Site, thus reducing exposures of potential receptors to contamination. The objectives of institutional controls are to prevent exposure to contaminant concentrations, control future development that could result in increased risk of exposure, and prevent the installation of new drinking water wells within contaminated areas. The effectiveness of selected institutional controls depends on their continued implementation, and their reliability depends on future compliance with the restrictions and inspections that are enforced.

The types of institutional controls employed at the source area would include activity and use restrictions enacted through proprietary (e.g., easements, covenants) and /or governmental (e.g., zoning requirements) controls to prevent use of Site areas that would pose an unacceptable risk to receptors. Other controls could include restrictions on installation of drinking water wells and restrictions on groundwater use at locations within the contaminated areas. Information device controls (warning signs, advisories, additional public education, Notices of Environmental Contamination) would also be employed to limit exposures to contamination. As part of the selected alternative, some or all of the following measures would be implemented in all areas of the Site:

- Restrictions on drilling wells in contaminated areas
- Restrictions on groundwater use in contaminated areas
- Programs to increase community awareness of potential hazards of exposure to contaminant compounds, ways to prevent exposure, and information on the remedial measures that would be implemented as part of the selected alternative.

Groundwater use restrictions and well drilling permit restrictions would be implemented in coordination with the PREQB to prevent future use of contaminated groundwater.

Other measures such as increasing the awareness of the local community on ways to minimize potential exposure to contaminants during and after the implementation of remedial action would also be instituted as part of the alternatives.

4.3.1.2 Long-term Monitoring

Long-term monitoring would be performed in all three plumes at the Site. Long-term monitoring would include groundwater sampling and analysis to monitor contaminant concentrations and migration over time.

The objectives of the long-term monitoring program are as follows:

- Identify any potentially toxic and/or mobile transformation products
- Assess the effectiveness of remedial action implemented
- Verify that the extent of contamination is not expanding downgradient, laterally or vertically
- Verify no unacceptable impact to potential receptors
- Detect new releases of contaminants to the environment or migration of existing contamination that could impact potential receptors
- Demonstrate the efficacy of institutional controls that were put into place to protect potential receptors
- Verify attainment of RAOs

Monitoring data would be evaluated and used to make decisions regarding the adequacy and continuation of the monitoring program. Decisions resulting from the evaluation of the data may include:

- Continue monitoring program without change
- Modify the monitoring program
- Modify institutional controls
- Implement a contingency or alternative remedy
- Verify remedial goals have been met and terminate performance monitoring

The primary parameters to be monitored would be the COCs, geochemical indicators (e.g., oxidation-reduction potential, dissolved oxygen, pH), and hydrogeologic parameters (e.g., elevation of ground water in monitoring wells). Increases and decreases in monitoring frequency may occur over the life of the remedy in response to changes in Site conditions and monitoring needs.

For cost estimating purposes, quarterly monitoring has been assumed for the first two years, and annual monitoring thereafter until year 30. Monitoring would be for COCs, geochemical indicators, and hydrogeologic parameters. A network of sample locations, including additional monitoring wells that may be installed as part of the remedial action, would be monitored. These locations would be finalized after the completion of remedial design.

4.3.1.3 Five-Year Reviews

Five-year reviews would be performed by EPA in accordance with CERCLA requirements. As part of the five-year reviews, public health evaluations would be conducted that would allow EPA to assess the ongoing risks to human health and the environment posed by the Site. The evaluations would be based on the data collected during long-term monitoring. The Site review would include a Site-wide visual inspection and a report prepared by EPA.

4.3.2 Alternative 1 – No Action

4.3.2.1 Detailed Description of Alternative 1

The No Action alternative is retained for comparison purposes as required by the NCP. No remedial action would be implemented as part of this alternative. It does not include any institutional controls or monitoring program. Five-year reviews would be conducted by EPA to assess Site conditions. No cost is included in the FS for five year reviews since it would be performed by EPA.

4.3.2.2 Individual Evaluation of Alternative 1

Alternative 1 is evaluated using the seven criteria discussed in Section 4.1.

Overall Protection of Human Health and the Environment

The No Action alternative would not eliminate any exposure pathways or reduce the level of human health risk of the existing groundwater contamination. It also would not provide protection to human health. This alternative would rely on unmonitored natural attenuation processes to restore groundwater quality. Since the rate of restoration would be unknown, this alternative cannot be considered protective of the environment or human health. This alternative would not meet the RAOs.

Compliance with ARARs

This alternative would not achieve chemical-specific ARARs established for groundwater. Location- and action-specific ARARs do not apply to this alternative since no remedial action would be conducted.

Long-Term Effectiveness and Permanence

This alternative would not be considered a permanent remedy since no action would be implemented to reduce the level of contamination or verify any naturally occurring reduction. It would not have long-term effectiveness. The potential for exposure to contaminated groundwater to Site receptors would not be eliminated. The level and migration of contaminants would not be monitored. Even though natural attenuation processes are occurring, the effectiveness of these natural attenuation processes in reducing the migration of contaminants would remain uncertain.

Reduction of T/M/V through Treatment

No reduction of contaminant T/M/V through treatment would be achieved under this alternative. The total volume of contaminated groundwater might increase if natural attenuation processes are unable to contain the plume. The extent and effectiveness of the toxicity reduction pathway, biodegradation of chlorinated contaminants, would be unknown.

Short-Term Effectiveness

Since no remedial action would be implemented at the Site, this alternative would not pose short-term risks to on-Site workers or the community. It would not have adverse environmental impacts to habitat or vegetation at the Site.

Implementability

This alternative could be implemented immediately since no services or permit equivalency would be required.

Cost

There are no capital or O&M costs associated with this alternative.

4.3.3 Alternative 2 – MNA (all three plumes)

4.3.3.1 Detailed Description of Alternative 2

Alternative 2 relies upon naturally occurring destructive mechanisms (biodegradation) to address the cis-1,2-DCE and 1,1-DCE plumes and nondestructive mechanisms (dilution and dispersion) to address the PCE plume. Routine monitoring and contaminant concentration trend analysis are generally performed as part of the MNA response action to demonstrate that contaminants do not represent significant risk and that degradation is occurring.

Alternative 2 consists of the following major activities:

- Pre-design investigation/MNA study
- Institutional controls
- Long-term monitoring
- Five-year reviews

Pre-design Investigation/MNA Study

To help address the uncertainty surrounding contaminant concentration reduction via MNA, an MNA investigation would be required in order to provide information to better project the effectiveness of natural attenuation mechanisms at field scale and to confirm that active degradation of contaminants is occurring where needed. It is recommended that any study incorporate extensive monitoring within, at the boundaries, and downgradient of the capture zones. While a study would need to be conducted for a sufficient period of time to observe meaningful trends (i.e., several years), decision points and contingency plans can be included so that any unexpected increase in contaminant concentrations or off-Site migration of contamination could be quickly addressed. Numerical techniques would be applied to model the aquifer characteristics and plume behavior and assist in the design and evaluation of monitoring.

The key to the effectiveness of MNA is the ability of natural processes to reduce contaminant concentrations to acceptable levels in a reasonable time frame. Factors that may limit the applicability and effectiveness of the process include the need to collect data, the need for highly skilled data evaluators, and limiting natural attenuation to low risk situations.

Institutional Controls

This alternative would also involve implementation of institutional controls to limit and monitor activities on-Site. The objectives of institutional controls are to prevent prolonged exposure to contaminant concentrations, control future development, and prevent the installation of wells within the contaminated plume boundaries. The effectiveness of selected institutional controls would depend on their continued implementation.

The types of institutional controls employed at the Site would include activity and use restrictions enacted through proprietary (e.g., easements, covenants) and/or governmental controls to prevent use of the properties that would pose an unacceptable risk to receptors (i.e., for residential use). Other institutional controls could include restrictions on installation of drinking water and irrigation wells, restrictions on groundwater use at locations within the plume footprint, and restrictions on home or building construction within the plume footprint. Information institutional controls (e.g., warning signs, advisories, additional public education, deed notices, Notices of Environmental Contamination) would also be employed to limit access to contaminated groundwater.

The reliability of this alternative would be dependent on future compliance with the restrictions and inspections that are enforced.

Monitoring

The inclusion of an MNA investigation is linked to what can be considered the key component of an MNA alternative, its monitoring program. *Performance Monitoring of MNA Remedies for VOCs in Ground Water* (EPA 2004) provides a technical framework for developing a monitoring program for MNA remedies addressing VOCs in groundwater. The objectives of the MNA monitoring program would be as follows:

- Demonstrate that natural attenuation is occurring according to expectations
- Detect changes in environmental conditions that may reduce the efficacy of any of the natural attenuation processes
- Identify any potentially toxic and/or mobile transformation products
- Verify that the plume(s) is not expanding downgradient, laterally or vertically
- Verify no unacceptable impact to downgradient receptors, especially the supply wells
- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy
- Demonstrate the efficacy of institutional controls that were put into place to protect potential receptors
- Verify attainment of remediation objectives

As is the case for monitoring programs for other remedies, the MNA monitoring data would be evaluated and used to make decisions regarding the effectiveness of the MNA remedy, the effectiveness of institutional controls, the adequacy of the monitoring program, and the adequacy of the CSM for MNA. Decisions resulting from the evaluation of the data may include:

- Continue monitoring program without change
- Modify the monitoring program
- Modify institutional controls
- Implement a contingency or alternative remedy
- Verify remedial goals have been met and terminate performance monitoring

The primary parameters to be monitored would be VOCs, geochemical indicators of transformation processes (e.g., oxidation-reduction potential, dissolved oxygen, pH, nitrate, iron (II), sulfate, methane, ethane, ethene), and hydrogeologic parameters (e.g., elevation of groundwater in monitoring wells and piezometers, local rates and schedules of any irrigation that may be occurring, local precipitation data, and pumping rates and schedules for nearby wells). The presence and abundance of dehalogenating bacteria (DHC) can also be monitored. Several years of monitoring data are typically necessary for estimation of the Site variability and expected rates of change in groundwater flow, contaminant concentrations, and geochemistry (EPA 2004). Once Site characterization and initial performance monitoring activities have provided these data, monitoring frequency may be revised if trends are established and the remedy is progressing as expected. Increases and decreases in monitoring frequency may occur over the life of the remedy in response to changes in Site conditions and monitoring needs.

For cost estimating purposes, a monitoring network similar to those described for long-term monitoring is assumed. However, it is important to consider that a monitoring system designed for evaluating the performance of an MNA remedy may be different from a network established for earlier phases of Site characterization, the FS, or interim actions. Specification of the actual monitoring network design would need to reflect information and data obtained during the MNA investigation, including information and data that indicate natural attenuation occurs through active degradation and not solely via dilution and dispersion at the Site. If monitoring indicates that levels are not decreasing sufficiently, a contingency plan would need to be implemented. If asymptote contaminant concentration levels are achieved, an active remedy (e.g., targeted injection, etc.) may be necessary to achieve MCLs. The active remedy would be defined in the ROD, or if necessary, in a subsequent ROD amendment or ESD.

Five Year Reviews

In addition to the monitoring program, public health evaluations would be conducted every five years and would allow EPA to assess the ongoing risks to human health and the environment posed by the Site. The evaluations would be based on the data collected from media monitoring.

4.3.3.2 Individual Evaluation of Alternative 2

Overall Protection of Human Health and the Environment

MNA in the PCE plume and 1,1-DCE plume would provide overall protection of the environment and human health. Contamination from these plumes is not seeping into surface water, and historical data from the supply wells do not show concentrations in excess of the MCLs (Figures 1-2 and 1-3). For the PCE plume, PCE would disperse or be diluted to concentrations below the PRGs by the time it enters the Maunabo #1 supply well. In the 1,1-DCE plume, the hydrogeology is such that the contaminants are following the slope of the bedrock to a low point in the vicinity of the Rio Maunabo. A fraction of the plume mass is contributing to detectable levels of 1,1-DCE in Maunabo #4, but since this supply well is not downslope along the bedrock from the plume (it appears to be more cross-slope), concentrations above the PRGs are not expected to enter Maunabo #4.

In the cis-1,2-DCE plume, protection of the environment would be adequate since the plume is not discharging to surface water. However, MNA would not be protective of human health until concentrations in the plume are reduced to below the PRGs. It would be necessary to demonstrate through further data collection whether natural attenuation is sufficient to provide this protection. Although historical data in Maunabo #1 has not shown contaminants above the MCLs since 2006 (Figure 1-2), the cis-1,2-DCE plume is within the capture zone of Maunabo #1, and there are no observed hydrogeological barriers or diversions between the plume and the supply well. Over time, if native microbes are not sufficiently degrading VC and cis-1,2-DCE at a fast enough rate, the pumping in Maunabo #1 could eventually draw higher concentrations of these compounds into the well, potentially exceeding the MCLs.

During remediation, exposure to groundwater in all three plumes—beyond the exposure route of the existing supply wells—would be prevented through institutional controls.

Compliance with ARARs

Alternative 2 does not meet chemical-specific ARARs in the short term because COC concentrations would continue to exceed the PRGs in groundwater while natural attenuation is taking place. However, the existing concentrations of COCs may decrease to acceptable levels within a reasonable timeframe. If not, a contingency remedy would need to be implemented to meet chemical-specific ARARs. This alternative would follow health and safety requirements to meet the action-specific ARARs. There are no location-specific ARARs for this Site.

Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - Alternative 2 would provide long-term effectiveness and permanence for the PCE and 1,1-DCE plumes since natural attenuation processes including dilution and dispersion (both the 1,1-DCE plumes) and aerobic biodegradation (1,1-DCE plume) would permanently reduce concentrations in Site groundwater.

Adequacy of Controls - Institutional controls would prevent exposure to contaminated groundwater before the groundwater quality would be restored to PRGs. The long-term monitoring program and five-year review would assess the contamination conditions and determine the operational time frame of the remedy.

Reliability of Controls - In the cis-1,2-DCE plume, it would be necessary to demonstrate through an MNA investigation whether natural attenuation would be effective over the long term. The mass of cis-1,2-DCE would need to undergo stepwise degradation to first VC and then non-toxic ethene for MNA to be effective.

Reduction of T/M/V through Treatment

T/M/V in the PCE plume would not be reduced since only non-destructive attenuation processes would be relied upon to reduce concentrations. In the cis-1,2-DCE plume and 1,1-DCE plume, mobility would not be reduced. However, toxicity and volume would potentially be reduced by biodegradation. Testing would be required to demonstrate that the microbial community is sufficient to biodegrade the Site contaminants to non-toxic ethene. Unless a contingency remedy is implemented, this alternative would not include an active treatment to reduce T/M/V of COCs in groundwater.

Short-Term Effectiveness

No construction activities beyond the installation of monitoring wells would be required for Alternative 2, thus there would be limited short-term impacts to workers and the community from implementation. Level D personal protective equipment (PPE) would be required during sampling. For long-term monitoring to be conducted on private property, coordination and access would need to be obtained from private property owners. In addition, short-term protection would be afforded to the community through institutional controls.

In the cis-1,2-DCE plume, MNA may be ineffective in the short term because of the potential for VC generated in the plume by the biodegradation of cis-1,2-DCE to enter the Maunabo #1 supply well. Although VC has not been observed in Maunabo #1 above the MCLs in the past five years, conditions may be present such that VC generation within the plume would result in an exceedance of the MCL in Maunabo #1. The effectiveness of MNA cannot be determined without further monitoring in an MNA investigation.

Implementability

This Alternative is implementable. Additional data collection would be required in the cis-1,2-DCE and 1,1-DCE plumes to confirm microbial activity, presence of daughter products, and decreased concentrations within wells. Services and materials for this alternative would be readily available. No problems would be anticipated for the implementation and enforcement of institutional controls. Access agreements would be required to implement this alternative on private property.

Cost

The total present worth for Alternative 2 is $2.5 million. The estimated capital cost is $0.4 million, and the long-term monitoring cost is $2.1 million for 30 years. Detailed cost estimates are presented in Appendix A.

4.3.4 Alternative 3 – AS/SVE (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

4.3.4.1 Detailed Description of Alternative 3

Under Alternative 3, MNA would be implemented for the PCE and 1,1-DCE plumes as presented in Alternative 2, and AS/SVE would be implemented in the cis-1,2-DCE plume. A full description of the MNA-related components is provided in Section 4.3.3.1.

Alternative 3 consists of the following major activities:

- Pre-design investigation/MNA study
- AS pilot study
- Remedial design
- AS/SVE installation/operation
- Institutional controls
- Long-term monitoring
- Five-year reviews

As noted in Section 3, the mass collected by an SVE system would be very low and potentially below detection limits in the system effluent and below air quality discharge standards. The need for an SVE system should be evaluated thoroughly during remedial design.

Pre-Design Investigation/MNA Study

Further characterization of the cis-1,2-DCE plume would be necessary prior to design of the AS/SVE system in order to optimize the location of sparge points. For cost estimating purposes, it was assumed that the characterization would involve groundwater screening with direct push technology and the installation of additional monitoring wells.

AS Pilot Study

A pilot test would be required to determine the radius of influence of each sparge location and soil vapor extraction well, and consequently the number of sparge points needed. The pilot test would also evaluate the need for treatment of the collected vapors.

Remedial Design

Data obtained during the RI, pre-design investigation, and pilot study would be used to develop the detailed approach for Site remediation during the design. All aspects necessary for implementing the remedial action would be considered, including but not limited to: detailed layout of the treatment strategy and system, construction sequence, regulatory requirements, and cost estimates. For cost estimating purposes, it was assumed that sparge points would have a 10-foot radius of influence, and SVE wells would have a 20-foot radius of influence. The density and layout of the sparge locations would be determined after the pre-design investigation further delineates the plume.

AS/SVE System Installation/Operation

For the purposes of this FS, it is assumed that an air sparge curtain would be installed upgradient of Maunabo #1 and a grid of sparge points would be installed in the upgradient portion of the cis-1,2-DCE plume. SVE wells would be installed to collect sparged vapors in the vadose zone. Collected vapors would be released directly to the atmosphere. For cost estimating purposes, it is assumed that the sparge grid would be operated for one year and the sparge curtain for three years. Performance monitoring would be conducted at groundwater monitoring wells installed in the sparge grid as well as upgradient and downgradient of the sparge curtain.

Institutional Controls

Alternative 3 would also involve implementation of institutional controls to control, limit, and monitor activities on-Site. The objectives of institutional controls would be to prevent prolonged exposure to contaminant concentrations, control future development, and prevent the installation of wells within the contaminated plume boundary. The effectiveness of selected institutional controls would depend on their continued implementation.

The types of institutional controls employed in the plume footprint would include activity and use restrictions enacted through proprietary (e.g., easements, covenants) and/or governmental (e.g., zoning requirements) controls to prevent use of the properties that would pose an unacceptable risk to receptors (i.e., for residential use). Other institutional controls could include restrictions on installation of aquifer drinking water or irrigation wells, restrictions on aquifer groundwater use at locations within the plume footprint, and restrictions on home or building construction within the plume footprint. Information institutional controls (e.g., warning signs, advisories, additional public education, deed notices, Notices of Environmental Contamination) would also be employed to limit access to contaminated groundwater.

Long-Term Monitoring

Monitoring is an essential component of engineered AS/SVE design and operation. Post-construction (long-term) monitoring is critical to ensure that the sparge curtain and grid are removing contaminants from the groundwater plume as planned. Since contaminants would remain on Site, a long-term groundwater monitoring program would be instituted to monitor groundwater contaminant concentrations and movement on Site. Groundwater samples from the monitoring well network would be collected annually and analyzed for COCs. The monitoring data would be evaluated and used to assess the effectiveness of the remedial alternative and to plan for further remedial action if required.

Five-Year Review

A five-year review would be conducted every five years using data obtained from maintenance and monitoring program. These reviews are important under this alternative because it is an additional mechanism to ensure the protection of human health and the environment. In this FS, it is assumed that the review would be conducted six times for the duration of 30 year FS evaluation period.

4.3.4.2 Individual Evaluation of Alternative 3

Overall Protection of Human Health and the Environment

This alternative would provide protection of human health and the environment. AS/SVE would remove the contaminants within the cis-1,2-DCE plume permanently; the remaining very low contaminant concentrations are expected to be reduced through natural processes such as dilution, dispersion, and biodegradation.

During remediation, exposure to groundwater in all three plumes—beyond the exposure route of the existing supply wells—would be prevented through institutional controls. This alternative would meet the RAOs. Institutional controls would eliminate the exposure pathway for contaminated groundwater to local receptors before the RAOs and the PRGs are achieved.

Compliance with ARARs

Alternative 3 would not meet chemical-specific ARARs in the short term in the PCE and 1,1-DCE plumes because COC concentrations would continue to exceed the PRGs in groundwater while natural attenuation is taking place. However, over time in all three plumes, the existing concentrations of COCs may decrease to acceptable levels within a reasonable timeframe by either AS/SVE or natural attenuation. If natural attenuation is not proceeding effectively, a contingency remedy would need to be implemented to meet chemical-specific ARARs. This alternative would follow health and safety requirements to meet the action-specific ARARs. There are no location-specific ARARs for this Site.

Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - AS/SVE would permanently remove contamination by stripping contaminants from groundwater. It is important to note that the proposed configuration of sparge points assumes that Maunabo #1 would continue operating as it currently operates. The sparge curtain layout is proposed in order to harness the hydraulic gradient created by the pumping to draw water into the sparge curtain treatment zone. If the well ceases pumping, the curtain would still be effective, but treatment would take a longer time since the groundwater flow velocity through the curtain would decrease. An additional factor to consider is aerobic biodegradation. Since VC and cis-1,2-DCE are known to be degradable by aerobic bacteria, the introduction of oxygen into the aquifer by the sparge system should stimulate the growth of aerobic bacteria capable of degrading these two compounds. Contaminants remaining outside the treatment zone are at low concentrations, and would be reduced over time through dilution and dispersion. Overall, this alternative provides an effective, permanent remedy for the cis-1,2-DCE plume.

Natural processes such as dilution, dispersion, and biodegradation would reduce concentrations permanently in the PCE and 1,1-DCE plumes.

Adequacy of Controls - Institutional controls would prevent exposure to contaminated groundwater before the groundwater quality would be restored to PRGs in each of the three plumes. The long-term monitoring program and five-year review would assess the contamination conditions and determine the operational time frame of the remedy.

Reliability of Controls – Institutional controls are considered reliable.

Reduction of T/M/V through Treatment

This alternative would significantly reduce the T/M/V of contamination in the cis-1,2-DCE plume. The volume and toxicity of contaminated groundwater would be reduced by the stripping of contamination from groundwater and soil. The mobility of soil vapor would be controlled by the vacuum applied to the treatment area, which would prevent vapor migration.

In the 1,1-DCE plume, mobility would not be reduced. However, toxicity and volume will potentially be reduced by biodegradation.

T/M/V would not be reduced in the PCE plume since the mechanisms of natural attenuation would be dilution and dispersion, and not biodegradation.

Short-Term Effectiveness

This alternative would have some short-term impacts to the community and the environment. AS/SVE would need to be installed and operated on the Site for approximately three years. Installation of the system would be performed without significant risks to the community. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards.

AS/SVE would be effective in the short term. VC and cis-1,2-DCE are volatile compounds that can be stripped relatively effectively from groundwater with sparging. The aerobic conditions in the groundwater created by the sparge system would induce a degree of biodegradation of the contaminants.

Implementing MNA in the PCE plume and 1,1-DCE plume would not be effective in the short term, since effectiveness would rely upon the dilution and dispersion created by groundwater flow and naturally occurring biodegradation to reduce concentrations to the PRG.

Implementability

MNA and AS/SVE are well established technologies and could be readily implemented at the Site. This alternative would require the use of readily available conventional construction and subsurface drilling equipment. Groundwater monitoring associated with MNA would be easily implementable using readily available services and materials.

Cost

The total present worth for Alternative 3 is $4.8 million. The estimated capital cost is $2.1 million, the present worth for O&M is $0.6 million, and present worth for long term monitoring is $2.1 million for 30 years. Detailed cost estimates are presented in Appendix A.

4.3.5 Alternative 4 – In-situ Bioremediation (cis-1,2-DCE plume) and MNA (PCE and 1,1-DCE plumes)

4.3.5.1 Detailed Description of Alternative 4

Alternative 4 includes the following components:

- Pre-design investigation
- Microcosm and pilot study

- Remedial Design
- In-situ bioremediation of cis-1,2-DCE plume
- Institutional controls
- Long-term monitoring
- Five-year reviews

Pre-Design Investigation

The objective of a pre-design investigation would be to fill data gaps and obtain design parameters for the completion of the remedial design. A pre-design investigation would include groundwater screening, well installation, and sampling. For cost estimating purposes, approximately 40 direct push groundwater screening locations would be implemented to define the treatment areas. One round of synoptic groundwater level measurements from the Site wells would be conducted. It is assumed that groundwater samples would be collected from 26 monitoring wells to update the contamination status. Numerical groundwater modeling would be performed to evaluate the aquifer characteristics and assist in the design of the injection scheme during the remedial design.

Microcosm and Pilot Study

A microcosm study would be necessary to evaluate various parameters prior to applying in-situ bioremediation in the field. Due to the presence of cis-1,2-DCE, the Adventus EHC® product is selected as the representative amendment for the bioremediation application. EHC® is a long-lasting amendment, but more difficult to distribute compared to the soluble amendments (lactate and whey). However, due to the presence of an active public water supply well in the vicinity of the treatment areas, a less mobile amendment like EHC® would be preferred for this Site. EHC® couples in-situ bioremediation with ZVI to treat the contaminant plume. EHC® is an integrated combination of controlled-release plant-derived carbon plus micro-scale ZVI particles specifically formulated for easy application via injection (Adventus, Josephine Molin). The microcosm study would investigate the effectiveness of various bioremediation amendments in treating Site contaminants. The microcosm study would evaluate the effectiveness of EHC® to promote combined abiotic and biotic degradation of key Site contaminants to non-toxic compounds. The microcosm study would also recommend the best biotic/abiotic amendment(s) for potential use at the Site. It is possible that bioaugmentation may be necessary to deliver contaminant-degrading bacteria (DHC) to the treatment zone.

A pilot study would be implemented to further evaluate the in-situ effectiveness of the selected amendment and to obtain design parameters, such as injection radius of influence, longevity in the subsurface, and the required quantity of DHC to support bioaugmentation. The actual selection of the amendment(s) and layout of the pilot study would be developed during the design stage. The final recommended amendment(s) for the remedial action would be selected during the remedial design.

Remedial Design

Data obtained during the RI, pre-design investigation, and pilot study would be used to develop the detailed approach for Site remediation during the design. All aspects necessary for implementing the remedial action would be considered, including but not limited to: detailed layout of the treatment strategy and system, construction sequence, regulatory requirements, and cost estimates.

In-situ Bioremediation for cis-1,2-DCE Plume

The details of the in-situ bioremediation program described below are preliminary, for cost estimating purposes, and would be subject to change based on the microcosm and pilot study results. Considering the longevity of the amendment and that diffusion processes play an important role in Site remediation, Adventus EHC® is selected as the representative amendment for treatment of the cis-1,2-DCE plume using bio- barriers. Each bio-barrier would consist of a series of injection points that would inject the EHC® amendment into the plume. Data obtained during the pilot study would also be used to select the formulation of EHC® specific to the Site. The final amendment for the RA would be selected during the RD.

To deliver EHC® slurry into the subsurface treatment zone, direct push technology or injection wells may be used. Direct push technology is assumed for cost estimating purposes in this FS. Rows of EHC® injection points using direct push technology would be proposed in areas where relatively high concentrations of cis-1,2-DCE were detected in this low concentration plume during the RI. Since the groundwater flows to the southwest influenced by regular and consistent pumping in Maunabo #1 and the general groundwater flow direction toward the Rio Maunabo, injection points would be proposed to be installed as shown in Figure 3-2. The layout of the injection points may change based on results of the remedial design.

It should be noted that the injection point layout and the EHC® loading would be biased toward areas with contaminant concentrations relatively higher than in other areas of this low concentration plume. The thickness of the treatment zone would also vary in accordance with contaminant distribution. For cost estimating purposes in this FS, the thickness of the treatment zone is assumed to be 15 feet and 30 injection wells have been estimated.

It is anticipated that the active treatment would require approximately one to two years followed by a long-term monitoring program. Due to the low contaminant concentrations at the Site, replenishment of amendment would likely not be necessary. For cost estimating purposes, it is assumed that the treatment areas in the cis-1,2-DCE plume would be treated one time with EHC®.

To monitor the effectiveness of in-situ bioremediation, a monitoring network would be established. In addition to existing monitoring wells, monitoring wells would also be installed within the treatment zone and downgradient of the injection wells for the cis-1,2-DCE plume. For cost estimating purposes, installation of 10 new monitoring wells is assumed.

Groundwater samples would be collected upgradient, within, and downgradient of the treatment zones and analyzed for COCs, metals, wet chemistry parameters (total organic carbon [TOC], alkalinity, nitrate/nitrite, chloride, bromide, sulfate, ferrous iron, methane/ethane/ethene [MEE], and pH), and field parameters (pH, dissolved oxygen, oxidation-reduction potential, temperature, conductivity) for the evaluation of biodegradation and attenuation. Groundwater samples would also be collected from selected wells and analyzed for DHC. For cost estimating purposes, it is assumed that the samples would be collected prior to the remedial action, then annually for the first five years. The final sampling frequency would be determined and adjusted during the course of monitoring in accordance with the contaminant concentrations trends and the rate of consumption of the amendment.

Institutional Controls

Alternative 4 would also involve implementation of institutional controls to control, limit, and monitor activities on-Site. The objectives of institutional controls are to prevent prolonged exposure to contaminant concentrations, control future development, and prevent the installation of wells within the contaminated plume boundary. The effectiveness of selected institutional controls would depend on their continued implementation.

The types of institutional controls employed at the source area would include activity and use restrictions enacted through proprietary (e.g., easements, covenants) and /or governmental (e.g., zoning requirements) controls to prevent use of the properties that would pose an unacceptable risk to receptors (i.e., for residential use). Other institutional controls could include restrictions on installation of aquifer drinking water wells or irrigation wells, restrictions on aquifer groundwater use at locations within the plume footprint, and restrictions on home or building construction within the plume footprint. Information institutional controls (e.g., warning signs, advisories, additional public education, deed notices, Notices of Environmental Contamination) would also be employed to limit access to contaminated groundwater.

Long-Term Monitoring

A long-term monitoring program would be established to evaluate the concentration changes and migration of contaminants in the aquifer. Groundwater samples would be collected annually. The groundwater samples would be analyzed for COCs, and wet chemistry parameters, as described above. Groundwater samples would include analysis of the degradation products of PCE, 1,1-DCE, and cis-1,2-DCE, to ensure that degradation of COCs is occurring.

An annual groundwater monitoring report would be prepared to evaluate the contaminant concentration trends, the potential natural attenuation processes, and their impact to the contaminant plume.

Five-Year Review

A review of Site conditions would be conducted every five years using data obtained from the annual sampling program. The Site reviews would include an evaluation of the extent of contamination and an assessment of contaminant migration and attenuation over time. The long-term groundwater monitoring program would be modified based on the monitoring results.

4.3.5.2 Individual Evaluation of Alternative 4

Alternative 4 is evaluated using the seven criteria discussed in Section 4.1.

Overall Protection of Human Health and the Environment

This alternative would provide protection of human health since institutional controls would be implemented to eliminate exposure pathways to Site contaminants. The alternative would also provide protection to the environment. Only bio-amendments that are safe to be injected into the aquifer near a public supply well will be considered and further evaluated during the microcosm study. Remediation of the cis-1,2-DCE plume would significantly reduce groundwater contamination in the treatment area using in-situ bioremediation. Any residual contamination in all three plumes would gradually reduce in concentration through natural attenuation processes, including degradation, dilution, and dispersion. Long-term monitoring would assess the changes in contaminant concentrations over time. This alternative would meet the RAOs.

Compliance with ARARs

This alternative would meet the chemical-specific ARARs over the long term. Implementation of in-situ bioremediation would significantly reduce contaminant concentrations in the treatment area. The residual contamination in groundwater in all three plumes would gradually reduce to meet the PRGs through natural attenuation processes.

The action-specific ARARs would be met. Permits would be obtained and permit requirements would be followed for the injection of amendment. A comprehensive health and safety plan would be developed and executed to cover every remedial activity. Remedial operations would be inspected and documented regularly. This alternative would involve shipment of a large quantity of amendment. Applicable DOT requirements for transporting and storing material for the remedial action would be followed. Table 2-3 summarizes the requirements of the action-specific ARARs and their FS considerations.

There are no location-specific ARARs for this Site as discussed in Section 2.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk - This alternative would have long-term effectiveness and permanence for treating the contamination in the cis-1,2-DCE plume. The active implementation of in-situ bioremediation could effectively reduce the contaminant mass. Remaining low contaminant concentrations in all three plumes would be further degraded through natural attenuation processes by biotic or abiotic destructive degradation processes or by dilution and dispersion as discussed in Section 2.

Adequacy of Controls - Institutional controls would prevent exposure to contaminated groundwater before the groundwater quality would be restored to PRGs. The long-term monitoring program and five-year review would assess the contamination conditions and determine the operational time frame of the remedy.

Reliability of Controls - In-situ bioremediation has been established over the past 10 years as an effective treatment technology for chlorinated solvent contamination in groundwater, such as at the Site.

Reduction of T/M/V through Treatment

In-situ bioremediation would significantly reduce the toxicity and volume of contamination in the cis-1,2-DCE plume. Chlorinated VOCs would be biotransformed to ethene and ethane. In the 1,1-DCE plume, mobility would not be reduced. However, toxicity and volume would potentially be reduced by biodegradation.

T/M/V would not be reduced in the PCE plume since the mechanisms of natural attenuation would be dilution and dispersion, and not biodegradation.

Short-term Effectiveness

The EHC® could be injected as a bio-barrier in the vicinity of MW-I and south of the perimeter of the PRB facility inward to minimize contaminant migration caused by displacement.

This alternative would have some short-term impacts to the community and the environment. Amendment injections would likely be completed in one month. Installation of injection wells or points would be performed without significant risk to the community. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards.

Implementing MNA in the PCE plume and 1,1-DCE plume would not be effective in the short term, since effectiveness would rely upon the dilution and dispersion created by groundwater flow and naturally occurring biodegradation to reduce concentrations to the PRG.

Implementability

This alternative would be technically implementable. A microcosm and pilot study would be implemented to obtain Site-specific information for the full scale remediation. Administrative difficulties can be anticipated from the Commonwealth of Puerto Rico to get approval on injecting bio-amendments in the waters of Puerto Rico, especially near a public supply well.

Services and materials for implementation of this alternative are readily available. Competitive bids would be obtained from a number of equipment vendors and remediation contractors. No problems are anticipated for the implementation and enforcement of the institutional controls.

Access agreements would be required to implement this alternative on private property.

Cost

The total present worth for Alternative 4 is $4.5 million. The estimated capital cost is $2.4 million, and the present worth for long term monitoring is $2.1 million for 30 years. Detailed cost estimates are presented in Appendix A.

4.4 Comparative Analysis of Remedial Alternatives

4.4.1 Overall Protection of Human Health and the Environment

Alternative 1 would not meet the RAOs and would not be protective of human health and the environment since no action would be taken. Contamination would remain in the groundwater, while no mechanisms would be implemented to prevent exposure to contaminated groundwater, or to reduce the T/M/V of contamination except through natural attenuation processes, which would not be monitored to assess the effectiveness or predict the duration of this alternative.

Alternative 2 would meet the RAOs. It is important to note that although historical data in Maunabo #1 have not shown contaminants above the MCLs since 2006 (Figure 1-2), the cis-1,2-DCE plume is within the capture zone of Maunabo #1. If natural attenuation does not occur within a reasonable time frame, there is the potential that the concentrations above the PRGs that are currently present in the plume would enter the Maunabo #1 supply well in the future, potentially impacting human health. Additional data collection would be needed to confirm that concentrations are decreasing through natural attenuation and the PRGs would be met within a reasonable timeframe. Similarly for the PCE and 1,1-DCE plume, it is uncertain if natural attenuation is occurring at a great enough rate to permanently reduce concentrations to below the PRGS within a reasonable timeframe.

Alternatives 3 and 4 will meet the RAOs. The AS/SVE system for Alternative 3 and the bio-barriers in Alternative 4 would each serve to reduce the concentration of contaminants in groundwater being drawn into the Maunabo #1 supply well, providing immediate protection of human health. Only bio-amendments that are safe to be injected into the aquifer near a public supply well will be considered and further evaluated during the microcosm study.

Alternatives 2, 3, and 4 would provide adequate control of risk to human health by implementing institutional and engineering controls.

4.4.2 Compliance with ARARs

Alternative 1 would not achieve chemical-specific ARARs established for groundwater. Location- and action-specific ARARs do not apply to this alternative since no remedial action would be conducted. For Alternative 2, further data collection would be needed to confirm the ability of natural attenuation to reduce concentrations and comply with ARARs. If natural attenuation does not occur within a reasonable time frame, ARARs would not be met. This is true also of the PCE and 1,1-DCE plumes for Alternatives 3 and 4. For the cis-1,2-DCE plume, these two alternatives would meet the chemical-specific ARARs over the long-term because implementation of AS/SVE or in-situ treatment processes would significantly reduce contaminant concentrations in the treatment area. There are no location-specific ARARs for this Site as discussed in Section 2. Alternatives 2 through 4 would comply with action-specific ARARs as summarized in Table 2-3.

4.4.3 Long-Term Effectiveness and Permanence

Alternative 1 would not be effective or permanent since there would be no mechanisms to prevent exposure to contaminated groundwater. Alternative 2 would provide long-term effectiveness and permanence by relying on natural attenuation to permanently reduce contaminant concentrations in the three plumes. However, for the cis-1,2-DCE and 1,1-DCE plumes, it is uncertain if natural attenuation is occurring at a great enough rate to reduce concentrations to below the PRGs within a reasonable time frame. Since the cleanup duration is indefinite, the monitoring period is assumed to be 30 years for costing purposes (assumptions for this FS are listed in Section 3.2). Alternatives 3 and 4 differ from Alternative 2 by using active in-situ treatment to reduce the contaminant mass in the treatment area. Alternatives 3 and 4 would provide the greatest permanent mass reduction of contamination within the cis-1,2-DCE plume within the shortest period of time: approximately 3 years for Alternative 3 and two years for Alternative 4. Remaining low contaminant concentrations in all three plumes would be reduced through natural attenuation processes.

Institutional controls in Alternatives 2, 3 and 4 would prevent exposure to contaminated groundwater while groundwater quality is restored via natural attenuation processes. The long-term effectiveness of the selected alternative would be assessed through routine groundwater monitoring and five year reviews.

4.4.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Alternative 1 would not reduce the contaminant T/M/V since no remedial action would be conducted. For Alternative 2, the total volume of contaminated groundwater in all three plumes might increase if natural attenuation processes are unable to contain the plume. The extent and effectiveness of toxicity reduction pathways via natural attenuation, especially on-going biodegradation of chlorinated contaminants, would need to be verified with further data collection. Alternatives 3 and 4 would be the most effective in reducing toxicity and volume of contamination through treatment in the cis-1,2-DCE plume. Furthermore, the sparge curtain (Alternative 3) and bio-barriers (Alternative 4) would serve to limit the mobility of the cis-1,2-DCE plume beyond its existing footprint. In the 1,1-DCE plume, mobility would not be reduced via Alternative 3 or 4. However, toxicity and volume will potentially be reduced by biodegradation. T/M/V would not be reduced in the PCE plume since the mechanisms of natural attenuation would be dilution and dispersion, and not biodegradation.

4.4.5 Short-Term Effectiveness

With respect to Alternative 1, there would be no short-term impact to the community and environment as no remedial action would occur. For long-term monitoring to be conducted on private property, coordination and access would need to be obtained from private property owners. There would be short-term impacts to the local community and workers for Alternatives 3 and 4 in the cis-1,2-DCE plume due to the active remedial actions undertaken and associated construction, operation, and/or injection activities. Implementing MNA in the PCE plume and 1,1-DCE plume would not be effective in the short term, since effectiveness would rely upon the dilution and dispersion created by groundwater flow and naturally occurring biodegradation to reduce concentrations to PRGs. Air monitoring, engineering controls, and appropriate worker PPE would be used to protect the community and workers for Alternatives 2 through 4.

4.4.6 Implementability

Alternative 1 would be easiest both technically and administratively to implement as no additional work would be performed at the Site. Alternatives 2 through 4 would be technically implementable since services, materials, and experienced vendors would be readily available. Bench and pilot studies would be implemented to obtain Site-specific design parameters. Access agreements would be required to implement the selected alternative on private properties. A permit would also be required to inject bioremediation amendment into the subsurface and/or to discharge vapor from an air sparge system to the atmosphere (if required). Overall, Alternative 4 would be the most difficult to implement, followed by Alternative 3, then Alternative 2.

4.4.7 Cost

A comparative summary of the cost estimates for each alternative is presented in Table 4-2. In summary, Alternative 1 has no cost. The total present worth costs for Alternative 2 is \$2.5 million, Alternative 3 is \$4.8 million and for Alternative 4 is \$4.5 million.

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Section 5

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Tables

Table 2-1
Chemical-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARAR	Status	Requirement Synopsis	Feasibility Study Consideration
Federal	National Primary Drinking Water Standards (40 CFR 141)- MCLs	Relevant and appropriate	Establishes health-based standards for public drinking water systems. Also establishes drinking water quality goals set at levels at which no adverse health effects are anticipated, with an adequate margin of safety.	The standards will be used to develop the PRGs to accommodate current and future use of Site groundwater as a source of drinking water supply.
Commonwealth of Puerto Rico	Puerto Rico Water Quality Standards Regulation, March 2010	See remarks under "Feasibility Study Consideration".	This regulation is to preserve, maintain and enhance the quality of the waters of Puerto Rico and prohibit any discharge of any pollutant to the waters of Puerto Rico by establishing water quality standards.. Water quality standards and use classifications are promulgated for the protection of the uses assigned to coastal, surface, estuarine, wetlands, and ground waters of Puerto Rico.	EPA has determined the PRWQS are neither applicable nor relevant or appropriate, since all remedial alternatives under consideration do not entail any discharges to any waters of Puerto Rico.

Acronyms:
ARARs - Applicable or Relevant and Appropriate Requirements
CFR - Code of Federal Regulations
PRGs - Preliminary Remediation Goals
MCLs - Maximum Contaminant Levels

Table 2-2
Location-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARARs	Status	Requirement Synopsis	Feasibility Study Consideration
Federal	Statement on Procedures on Floodplain Management and Wetlands protection (40 CFR 6 Appendix A)	Applicable	This Statement of Procedures sets forth Agency policy and guidance for carrying out the provisions of Executive Orders 11988 and 11990.	Alternatives will take into consideration floodplain management and wetland protection.
Federal	Policy on Floodplains and Wetland Assessments for CERCLA Actions (OSWER Directive 9280.0-12, 1985)	To Be Considered	Superfund actions must meet the substantive requirements of Executive Order 11988, Executive Order 11990, and 40 CFR part 6, Appendix A.	Alternatives will take into consideration floodplain management and wetland protection.
Federal (Non-Regulatory)	Wetlands Executive Order (EO 11990)	To Be Considered	Federal agencies are required to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance natural and beneficial values of wetlands.	Remedial alternatives that involve construction must include all practicable means of minimizing harm to wetlands. Wetlands protection considerations must be incorporated into the planning and decision making of remedial alternatives.
Federal	National Environmental Policy Act (NEPA) (42 USC 4321; 40 CFR 1500 to 1508)	To Be Considered	This requirement sets forth EPA policy for carrying out the provisions of the Wetlands Executive Order (EO 11990) and Floodplain Executive Order (EO 11988).	The requirement will be considered during the development of alternatives.
Federal	Clean Water Act (CWA) Section 404 (40 CFR 404)	Applicable	Under this requirement, no activity that adversely affects a wetland is permitted if a practicable alternative that does not affect wetlands is available. If no other practicable alternative exists, impacts on wetlands must be mitigated.	The effects on wetlands will be evaluated during the identification, screening, and evaluation of alternatives. Permits may be required for some alternatives.
Federal	National Historic Preservation Act (40 CFR 6.301)	To Be Considered	This requirement establishes procedures to provide for preservation of historical and archeological data that might be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program.	The effects on historical and archeological data will be evaluated during the identification, screening, and evaluation of alternatives.
Commonwealth of Puerto Rico	Act for the Protection and Preservation of Puerto Rico's Karst Region, August 21, 1999, No. 292	To Be Considered	This regulation requires the protection and conservation of the karst regions physiography; and prevent the transportation and sale of natural materials without permits.	The requirement will be considered during the development of alternatives.

Table 2-3
Action-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARARs	Status	Requirement Synopsis	Feasibility Study Consideration
General - Site Remediation				
Federal	OSHA Recording and Reporting Occupational Injuries and Illnesses (29 CFR 1904)	Applicable	This regulation outlines the record keeping and reporting requirements for an employer under OSHA.	These regulations apply to the companies contracted to implement the remedy. All applicable requirements will be met.
Federal	OSHA Occupational Safety and Health Standards (29 CFR 1910)	Applicable	These regulations specify an 8-hour time-weighted average concentration for worker exposure to various organic compounds. Training requirements for workers at hazardous waste operations are specified in 29 CFR 1910.120.	Proper respiratory equipment will be worn if it is not possible to maintain the work atmosphere below the 8-hour time-weighted average at these specified concentrations.
Federal	OSHA Safety and Health Regulations for Construction (29 CFR 1926)	Applicable	This regulation specifies the type of safety equipment and procedures to be followed during Site remediation.	All appropriate safety equipment will be on-site, and appropriate procedures will be followed during remediation activities.
Federal	RCRA Identification and Listing of Hazardous Wastes (40 CFR 261)	Applicable	This regulation describes methods for identifying hazardous wastes and lists known hazardous wastes.	This regulation is applicable to the identification of hazardous wastes that are generated, treated, stored, or disposed during remedial activities.
Federal	RCRA Standards Applicable to Generators of Hazardous Wastes (40 CFR 262)	Applicable	Describes standards applicable to generators of hazardous wastes.	Standards will be followed if any hazardous wastes are generated on-Site.
Federal	RCRA Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities – General Facility Standards (40 CFR 264.10–264.19)	Relevant and Appropriate	This regulation lists general facility requirements including general waste analysis, security measures, inspections, and training requirements.	Facility will be designed, constructed, and operated in accordance with this requirement. All workers will be properly trained.
Commonwealth of Puerto Rico	Regulation of the Puerto Rico Environmental Quality Board (PREQB) for the Prevention and Control of Noise Pollution	Applicable	This standard provides the standards and requirements for noise control.	This standard will be applied to any remediation activities performed at the Site.
Commonwealth of Puerto Rico	Puerto Rico's Anti-degradation Policy	Applicable	Conserve, maintain and protect the designated and existing uses of the waters of Puerto Rico. The water quality necessary to protect existing uses, including threatened and endangered species shall be maintained and protected.	The requirement will be considered during the development of alternatives. The potential effects of any action will be evaluated to ensure that any endangered or threatened species and their habitat will not be affected.

Table 2-3
Action-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARARs	Status	Requirement Synopsis	Feasibility Study Consideration
Waste Transportation				
Federal	Department of Transportation (DOT) Rules for Transportation of Hazardous Materials (49 CFR Parts 107, 171, 172, 177 to 179)	Applicable	This regulation outlines procedures for the packaging, labeling, manifesting, and transporting hazardous materials.	Any company contracted to transport hazardous material from the Site will be required to comply with this regulation.
Federal	RCRA Standards Applicable to Transporters of Hazardous Waste (40 CFR 263)	Applicable	Establishes standards for hazardous waste transporters.	Any company contracted to transport hazardous material from the Site will be required to comply with this regulation.
Waste Disposal				
Federal	RCRA Land Disposal Restrictions (40 CFR 268)	Applicable	This regulation identifies hazardous wastes restricted for land disposal and provides treatment standards for land disposal.	Hazardous wastes will be treated to meet disposal requirements.
Federal	RCRA Hazardous Waste Permit Program (40 CFR 270)	Applicable	This regulation establishes provisions covering basic EPA permitting requirements.	All permitting requirements of EPA must be complied with.
Commonwealth of Puerto Rico	PREQB Regulation for the Control of Non-Hazardous Solid Waste (November 1997)	Applicable	This regulation establishes standards for the generation, management, transportation, recovery, disposal and management of non-hazardous solid waste.	Control activities for the non-hazardous wastes must comply with the treatment and disposal standards.
Commonwealth of Puerto Rico	PREQB Regulation for the Control of Hazardous Solid Waste (September 1998)	Applicable	This regulation establishes standards for management and disposal of hazardous wastes.	All remedial activities must adhere to these regulations while handling hazardous waste during remedial operations.

Table 2-3
Action-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARARs	Status	Requirement Synopsis	Feasibility Study Consideration
Water Discharge or Subsurface Injection				
Federal	National Pollutant Discharge Elimination System (NPDES) (40 CFR 100 et seq.)	Relevant and Appropriate	NPDES permit requirements for point source discharges must be met, including the NPDES Best Management Practice (BMP) Program. These regulations include, but are not limited to, requirements for compliance with water quality standards, a discharge monitoring system, and records maintenance.	Project will meet NPDES permit requirements for point source discharges.
Federal	Safe Drinking Water Act – Underground Injection Control (UIC) Program (40 CFR 144, 146)	Relevant and Appropriate	Establish performance standards, well requirements, and permitting requirements for groundwater re-injection wells.	Project will evaluate the requirement for injection of reagent for in situ treatment.
Commonwealth of Puerto Rico	Puerto Rico Water Quality Standards Regulation, March 2010	See remarks under "Feasibility Study Consideration".	This regulation is to preserve, maintain and enhance the quality of the waters of Puerto Rico and prohibit any discharge of any pollutant to the waters of Puerto Rico by establishing water quality standards. Water quality standards and use classifications are promulgated for the protection of the uses assigned to coastal, surface, estuarine, wetlands, and ground waters of Puerto Rico.	EPA has determined the PRWQS are neither applicable nor relevant or appropriate, since all remedial alternatives under consideration do not entail any discharges to any waters of Puerto Rico.

Table 2-3
Action-specific ARARs, Criteria, and Guidance
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Regulatory Level	ARARs	Status	Requirement Synopsis	Feasibility Study Consideration
Off-Gas Management				
Federal	Clean Air Act (CAA)—National Ambient Air Quality Standards (NAAQs) (40 CFR 50)	Applicable	These provide air quality standards for particulate matter, lead, NO_2, SO_2, CO, and volatile organic matter.	During treatment, air emissions will be properly controlled and monitored to comply with these standards.
Federal	Standards of Performance for New Stationary Sources (40 CFR 60)	Applicable	Set the general requirements for air quality.	During treatment, air emissions will be properly controlled and monitored to comply with these standards.
Federal	National Emission Standards for Hazardous Air Pollutants (40 CFR 61)	Applicable	These provide air quality standards for hazardous air pollutants.	During treatment, air emissions will be properly controlled and monitored to comply with these standards.
Federal	Federal Directive - Control of Air Emissions from Superfund Air Strippers (OSWER Directive 9355.0-28)	Applicable	Provides guidance on control of air emissions from air strippers used at Superfund Sites for groundwater treatment.	During treatment, air emissions will be properly controlled and monitored to comply with these standards.
Commonwealth of Puerto Rico	PREQB Regulation for the Control of Atmospheric Pollution (1995)	Applicable	Describes requirements and procedures for obtaining air permits and certificates; rules that govern the emission of contaminants into the ambient atmosphere.	Need to meet requirements when discharging off-gas.

Acronyms:
ARARs - Applicable or Relevant and Appropriate Requirements
OSHA - Occupational Safety and Health Administration
CFR - Code of Federal Regulations
RCRA - Resource Conservation and Recovery Act
EPA - Environmental Protection Agency
NO_2 - Nitrogen dioxide
SO_2 - Sulfur dioxide
CO - Carbon monoxide
OSWER - Office of Solid Waste and Emergency Response

Table 2-4
Preliminary Remediation Goals for Groundwater
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Contaminants of Concern	National Primary Drinking Water Standards (EPA MCLs)[1] (µg/L)	PRGs[2] (µg/L)	Maximum Detected Concentrations[3]		
			PCE plume (µg/L)	cis-1,2-DCE plume (µg/L)	1,1-DCE plume (µg/L)
Volatile Organic Compounds					
Trichloroethene	5	5	1.9	1.6	-
Tetrachloroethene	5	5	8.5	7.6	-
cis-1,2-dichloroethene	70	70	0.56	300	0.38
1,1-dichloroethene	7	7	1.7	1.7	25
Vinyl Chloride	2	2	-	1.8	-

Notes:
1. EPA National Primary Drinking Water Standards (web page), EPA 816-F-09-004, May 2009.
2. Based on the EPA MCLs.
3. The maximum concentrations detected at the Site during Rounds 1 and 2 monitoring well sampling events. Highlighted concentrations indicate exceedances over PRGs.

Acronyms:
EPA - United States Environmental Protection Agency
MCLs - Maximum Contaminant Levels
PRGs - Preliminary Remediation Goals
µg/L - microgram per liter
NL - not listed
PCE - tetrachloroethene
cis-1,2-DCE - cis-1,2-dichloroethene
1,1-DCE - 1,1-dichloroethene

Table 2-5
Groundwater Technology Screening
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

General Response Action	Remedial Technology	Process Option	Description of Response Action	Effectiveness	Technical Implementability	Relative Cost	Retained for cis-1,2-DCE Plume	Retained for PCE Plume	Retained for 1,1-DCE Plume
No Action	None	None	The No Action alternative is retained as a baseline for comparison with other alternatives as required by National Contingency Plan (NCP). No remedial actions would be implemented. The Site-wide groundwater contamination would remain in its existing condition.	The No Action Response is not effective. It does not prevent human exposure to contaminated groundwater. It does not protect the environment. It does not meet the remedial action objectives (RAOs).	Implementable. Minor administrative action may be needed.	No capital, operation, or maintenance costs.	Yes	Yes	Yes
Long-Term Monitoring	Long-Term Monitoring	Long-Term Monitoring	Periodic environmental monitoring to determine extent of contaminant plume.	Not effective in reducing contamination levels by itself. Would not alter the risk to human health or the effect on the environment. Natural attenuation processes would decrease groundwater contaminant concentrations and potentially decrease toxicity. Effective in providing information on Site conditions.	Easily implementable. Comprehensive monitoring well network needs to be installed for the long-term monitoring program.	Medium capital cost if monitoring well network needs to be established. Medium operation and maintenance (O&M) costs.	Yes	Yes	Yes
Institutional/Engineering Controls	Institutional Controls	Deed Restrictions	Deed restrictions are used to prevent certain types of uses for properties where exposure pathways to contaminants may be created as a result of those uses. They may be used to require the installation of a vapor mitigation system; or prevent well drilling activities within the contamination plume. They are generally administrated by local government.	Effective in reducing risks to human health by restricting or eliminating use of contaminated groundwater. The effectiveness depends on proper enforcement. Would not reduce the migration and environmental impact of the contaminated groundwater in any of the contaminant plumes.	May not be easy to implement. Their implementability highly depends on the local government and its enforcement system.	Implementation cost is low. Some administrative, long-term monitoring and periodic assessment costs would be required.	Yes	Yes	Yes
		Well Drilling Restrictions	This process involves regulatory actions that regulate the installation of wells. PREQB has the administrative authority to prevent installation of drinking water wells in contaminated areas.	Effective for protection of human health by preventing direct contact with contaminated groundwater in all three plume areas. Would not reduce migration or environmental impact of the contaminated groundwater in any of the contaminant plumes.	Implementable via the existing permitting process. May be combined with other remediation activities as a protective measure to prevent exposure to contaminants during and post remediation.	Implementation cost is low.	Yes	Yes	Yes
	Engineering Controls	Public Water Supply Management	Maunabo #1 and #4 supply wells are part of the Maunabo public water supply. The public water supply system would be evaluated to identify operating scenarios whereby the groundwater contamination would not impact human health. These scenarios may include taking the wells offline or alternate supply such as surface water or bottled water.	Effective for protection of human health by managing the water supply such that consumers are not exposed to groundwater above the PRGs. Would not reduce migration or environmental impact of the contaminated groundwater in any of the contaminant plumes. Ineffective in meeting water usage needs of the population in Maunabo.	Since the public supply wells cater to almost 60 percent of the water needs for the population in Maunabo, turning off the wells is not feasible. Providing an alternate water supply is impractical and not cost-effective.	Costs will depend upon operating scenarios.	No, due to implementability concerns	No, due to implementability concerns	No, due to implementability concerns
	Community Awareness	Information and Education Programs	Community information and education programs would be undertaken to enhance awareness of potential hazards, available technologies capable to address the contamination, and remediation progress to the local community.	Educational programs would protect human health by creating awareness and would enhance the implementation of deed restrictions within the contaminated aquifer.	Implementable.	Low capital cost and operational costs.	Yes	Yes	Yes
Monitored Natural Attenuation (MNA)	MNA	MNA	Rely on natural destructive (biodegradation and abiotic degradation) and nondestructive mechanisms (dilution, dispersion, volatilization, and adsorption) to reduce contaminant levels within a reasonable time frame. Implemented with a long-term monitoring program. Under favorable conditions, these physical, chemical, or biological processes act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater.	Effective for sites where multiple years of data have demonstrated that the contaminant plume is contained or shrinking; destructive attenuation mechanisms are active and responsible for containing the plume; and sufficient evidence exists that these mechanisms would persist for the required time of plume management. Sampling results suggests biodegradation has been occuring in the cis-1,2-DCE plume and abiotic degradation has occurred in the 1,1-DCE plume. Under favorable conditions, these processes can be effective in containing and remediation of contamination, in a reasonable timeframe. The redox conditions of the low concentration PCE plume are likely to be conducive to natural nondestructive mechanisms. Supplementary studies will be required to sufficiently demonstrate the effectiveness of natural attenuation.	Materials and services necessary to model and monitor the contaminant dynamics are readily available. Institutional/engineering controls would be required to minimize human exposure to contaminants. Due to the low contaminant concentrations at this Site, MNA would be implemented as a stand-alone remedy, in conjunction with active remediation or as a follow up to a remedial action.	Medium capital costs to fully understand the CSM. Medium O&M cost.	Yes	Yes	Yes

Table 2-5
Groundwater Technology Screening
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Maunabo, Puerto Rico

General Response Action	Remedial Technology	Process Option	Description of Response Action	Effectiveness	Technical Implementability	Relative Cost	Retained for cis-1,2-DCE Plume	Retained for PCE Plume	Retained for 1,1-DCE Plume
Containment	Vertical Barrier	Slurry Walls	Slurry walls are constructed by making low-permeability slurry (typically either a soil-bentonite mixture or a cement-bentonite mixture) in an excavated trench. Excavation can be completed using a long-arm excavator and a clam shovel to achieve the required depth. Slurry would be pumped into the hole during the course of excavation to keep the sidewalls from collapsing.	Eliminates migration of contaminated groundwater horizontally and reduces mobility of the plume. Slurry wall barriers are effective in preventing additional groundwater contamination from migrating off-Site or for diverting uncontaminated groundwater around a contaminant source. Effectiveness is limited if a confining layer is not continuous below source area. Use of this technology does not guarantee that further remediation may not be necessary and there is potential for the slurry wall to degrade or deteriorate over time. In addition, there is potential for contaminated groundwater to flow around the barrier. Mobilization of contaminated groundwater to the Rio Maunabo is highly undesirable.	Slurry walls are constructible at this Site. Construction materials and services are readily available. Typical slurry wall applications reach installation depths of about 30 to 40 feet bgs, based upon practical limitations associated with excavator trenching. Slurry walls can be installed to depths of 100 feet bgs using a clam shovel at a higher unit cost. If a downgradient slurry wall is used to contain the plume, then additional technologies such as groundwater extraction would be necessary to control groundwater levels at the Site and reduce the likelihood of groundwater flowing around the wall.	Moderate to high capital cost.	No, due to lack of its effectiveness	No, due to lack of its effectiveness	No, due to lack of its effectiveness
		Sheet Pile Barriers	Sheet pile barriers are constructed by driving or vibrating sections of steel sheet piling into the ground. Each sheet pile section is interlocked at its edges, and the seams are often grouted to prevent leakage. Upon completion of remedial activities, the sheet piles can be vibrated out of the ground, disassembled, and removed from the Site, provided that the sheeting and joints are still of good structural integrity at the time of removal. Otherwise, the sheets would be cut off below ground surface, and the walls would continue to influence groundwater flow patterns on a localized scale.	Eliminates migration of contaminated groundwater horizontally and reduces mobility of the plume. Installing sheet pile walls might enhance the vertical gradient, thus enhancing the contaminant migration into the bedrock aquifer, which is highly undesirable. If good, non-leaking, joints are installed, the sheet piling may be effective in preventing additional groundwater contamination from migrating off-Site or for diverting uncontaminated groundwater around a contaminant source. Effectiveness is limited if joints are leaking. Use of this technology does not guarantee that further remediation in the future may not be necessary. Installing sheet pile walls in a plume with an uncertain source will reduce its effectiveness. In addition, there is potential for contaminanted groundwater to flow around the wall.	Sheet pile walls are implementable at the Site in terms of constructability. Sheet piles have been widely used in the heavy construction industry, particularly for groundwater control and slope stability. Construction materials and services are readily available. Typical sheet pile wall applications reach installation depths of approximately 80 feet bgs, based upon practical limitations associated with installation. Completely watertight joints are nearly impossible to install.	Moderate to high capital cost, depending upon the depth to which the walls are installed.	No, due to lack of its effectiveness	No, due to lack of its effectiveness	No, due to lack of its effectiveness
Extraction	Groundwater Extraction	Extraction Wells	Installation of groundwater extraction wells to provide hydraulic control and capture of contaminant migration. Effective when combined with other treatment and discharge technologies. Potential scenarios for extraction wells include containment of source area groundwater, containment of the leading edge of the high concentration plume, or preventing contaminated groundwater from migrating off-Site.	Effective in providing hydraulic control and removal at sites where the soil is highly permeable, hydrogeology is well understood and the pumping rate necessary to maintain hydraulic control is sustainable. Reduces migration of contaminated groundwater and reduces concentrations of contaminants in groundwater over time. Must be combined with treatment and disposal. Due to the moderate to high yield observed from wells at the Site, moderately permeable soil and the abundance of groundwater in an alluvial aquifer, extraction wells can be installed at the Site. However, the extraction wells would be competing with the public supply wells and would possibly decrease the production rate of Maunabo #1 and Maunabo #4, which would impact effectiveness.	Implementable. Necessary equipment and materials are readily available.	Medium to high capital cost due to depth of drilling. Medium O&M cost due to prolonged period of operation generally required.	No, due to lack of its effectiveness	No, due to lack of its effectiveness	No, due to lack of its effectiveness
		Extraction Trenches	Extraction trenches are constructed perpendicular to the direction of groundwater flow to intercept and prevent downgradient migration of a contaminant plume. A bio-polymer slurry is used to temporarily support the sidewalls of the trench. The trench is typically backfilled with material of higher permeability than the native aquifer (e.g., gravel) to create a zone of preferential flow, and perforated piping or well screens are typically installed in the trench to collect the intercepted groundwater. Extracted groundwater is then treated as necessary to meet discharge requirements. Extraction trenches are generally used for contamination at shallow depth.	Effective in capturing groundwater to provide hydraulic control. Not typically installed at depths greater than 30 feet bgs due to trenching equipment limitations. The contaminant plume at the Site is deeper than 30 feet, therefore extraction trenches would not be able to fully capture the contaminants.	Not easily implemented at deeper depths. Necessary equipment and materials are readily available.	High capital cost due to depth. Medium O&M cost.	No, due to lack of its effectiveness	No, due to lack of its effectiveness	No, due to lack of its effectiveness

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General Response Action	Remedial Technology	Process Option	Description of Response Action	Effectiveness	Technical Implementability	Relative Cost	Retained for cis-1,2-DCE Plume	Retained for PCE Plume	Retained for 1,1-DCE Plume
Treatment	Ex-situ Treatment	Air Stripping	Air stripping is a physical mass transfer process that uses clean air to remove dissolved volatile organic compounds (VOCs) from water by increasing the surface area of the groundwater exposed to air. In general, the water stream exiting the air stripper can be discharged to surface water or groundwater. The vapor effluent would likely require treatment (e.g., carbon adsorption or thermal or catalytic oxidation) before discharge to the atmosphere.	Effective in removing VOCs from water. The Henry's law constants for most of the Site contaminants indicates that these can be removed in the air stripper. Contaminants extracted from the contaminant plumes could be effectively treated. The process is susceptible to inorganic fouling and may require pretreatment steps such as pH adjustment or annual maintenance such as acid cleaning of the air stripper interior. Based on the low contaminant mass in the plumes, off-gas will likely not require treatment prior to discharge.	Implementable. Vendors and equipment are readily available to provide air strippers for groundwater VOC removal. Needs to be implemented with groundwater extraction and discharge technologies. May require permit for discharge of VOCs to the atmosphere and/or off-gas treatment (i.e., vapor phase carbon) prior to discharge.	Low capital and low O&M costs.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.
		Granular Activated Carbon (GAC) Adsorption	Extracted groundwater or off-gas is pumped through vessel(s) containing GAC to which contaminants adsorb and are removed. When the concentration of contaminants in the effluent exceeds a pre-established value (berakthrough), the GAC is removed for regeneration or disposal.	Protects human receptors by reducing concentrations in groundwater. Effective in removing contaminants with moderate or high organic carbon partition coefficients (K_{oc}) from groundwater. Not effective in removing VC, which does not effectively adsorb to carbon. Not very effective in removing cis-1,2-DCE which has the tendency to break through quickly. May be susceptible to biological and inorganic fouling. Particularly effective for polishing water discharges from other technologies to attain regulatory compliance.	Implementable. The equipment and materials are readily available. Logistic and economic disadvantages arise from the need to transport and decontaminate spent carbon. Costs are high if it is used as the primary treatment on waste streams with high contaminant concentration levels. It would need to be combined with groundwater extraction and discharge technologies. O&M requirements include monitoring of influent and effluent streams, regeneration and replacement of carbon, and backwashing.	Medium capital and O&M costs.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.
		Ultraviolet (UV) /Oxidation	Extracted groundwater is transferred to a reactor where it is combined with ozone and/or hydrogen peroxide and irradiated with UV light. Organic contaminants are destroyed as a result of the synergistic action of the oxidant with UV light. System may require off-gas treatment to destroy unreacted ozone and volatilized contaminants. This process option is used when destruction of contaminants is preferred or when contaminants cannot be removed with GAC or air stripping.	Effective in treating chlorinated VOC contaminants including VC, in groundwater extracted from the contaminant plumes of the Site. Aqueous stream must have good transmissivity; high turbidity causes interference. This technology would not be cost effective to treat contaminants extracted from a low concentration plume such as at the Site.	Implementable. Vendors and equipment are readily available. Can be implemented with groundwater extraction and discharge technologies. Minor administrative difficulties anticipated for implementation of a UV oxidation system; may require permit for discharge of unreacted ozone and volatilized VOCs. Alternatively, treatment of off-gas may be required.	High capital and O&M costs. Generally, more costly than an equivalently sized GAC unit. Requires more electricity to operate.	No, due to high costs and electricity demand	No, due to high costs and electricity demand	No, due to high costs and electricity demand
	In-situ Treatment	In-situ Thermal Remediation	Heat is transferred to the subsurface, causing VOCs to vaporize and evaporate. Heat can be delivered by steam, conduction or by electrical resistivity heating (ERH). ERH raises the temperature of groundwater, increasing volatilization of contaminants that are removed in vapor phase. Direct injection of steam into an aquifer through injection wells, vaporizes the contaminants which are then removed by vacuum extraction and treated. Steam enhanced extraction raises the soil temperature across the treatment volume, causes groundwater to boil and generates steam in-situ which results in steam distillation of the contaminants.	Successfully applied in removing contamination sources in silty or clayey soils. Its effectiveness would be impacted if applied in plumes where the source is uncertain, such as at the Site. Residual heat would also be capable of stimulating accelerated biodegradation of remaining low-concentration contaminants. Typically used for treating contaminant source areas rather than larger, less contaminated plumes such as at the Site. If too much unheated water enters the treatment zone from upgradient, it can create a significant heat sink, which decreases the efficiency of the technology. Efficiency is highly dependent on the nature of the subsurface and heterogeneity of the soils.	Implementable by specialty vendors. The technology requires a significant, reliable source of electrical power in order to provide capacity to heat groundwater, especially to reach deeper depths. PRWQS Regulation state that no heat may be added to the waters of Puerto Rico, which would cause the temperature of any site to exceed 90°F or 32.2°C.	High capital and O&M costs over a short period, approximately one or two years.	No, due to high costs, effectiveness and implementability concerns	No, due to high costs, effectiveness and implementability concerns	No, due to high costs, effectiveness and implementability concerns

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General Response Action	Remedial Technology	Process Option	Description of Response Action	Effectiveness	Technical Implementability	Relative Cost	Retained for cis-1,2-DCE Plume	Retained for PCE Plume	Retained for 1,1-DCE Plume
Treatment	In-situ Treatment	Air Sparging	Air sparging involves the injection of air or oxygen into the contaminated aquifer. Injected air strips organic contaminants in-situ and helps to flush the contaminants into the unsaturated zone. If the mass of VOCs is great enough, SVE may be implemented in conjunction with air sparging to remove the vapor-phase contamination from the vadose zone by vacuum extraction and if required, vapor treatment to mitigate impacts to surface receptors. Based upon the relatively small contaminant mass in the plumes, an SVE system will likely not be required for this Site. The need for an SVE component is generally determined during a Site-specific pilot study. Oxygen in the air injected into contaminated groundwater can also enhance aerobic biodegradation of contaminants below and above the water table.	Protects human receptors by reducing concentrations of contaminants in groundwater. Effective for volatile, relatively insoluble organics. Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors. Depending upon the mass of sparged vapors, air sparging could increase exposure to surface receptors if not implemented in conjunction with SVE. Effectiveness largely depends upon distribution of contaminants, heterogeneity of the aquifer, preferential flow paths and the ability to actively direct contact of air with contaminated groundwater.	Implementable. System would likely not require off-gas treatment.	Moderate capital and O&M costs.	Yes	No, due to depth in aquifer and low total mass in this plume	No, due to depth in aquifer and low total mass in this plume
		In-situ Chemical Reduction	The technology involves the injection of reductants such as nano-or micro-scale zero valent iron (ZVI) particles to reduce the contaminants to non-hazardous compounds.	A combination of ZVI with an organic substrate to stimulate anaerobic biodegradation would have the potential to treat Site contaminants. Protects human receptors by reducing concentrations of contaminants in groundwater. Achieving uniform delivery of reductant and adequate contact of reductant with contaminants are critical for effective treatment, which rely on proper implementation of this technology. Reductant can be delievered using injection wells.	Implementable. Vendors and equipment are readily available. Liquid injection would be a method for delivering reductant in-situ.Treatability testing and pilot-scale testing will be required. May result in secondary water quality changes like increase in concentrations of Iron and Manganese in the groundwater. Potential impacts to the public water supply system will need to be evaluated prior to implementation.	Medium to high capital costs. Low O&M costs.	Yes, in combination with an organic carbon amendment to stimulate in-situ bioremediation.	No, due to lack of its effectiveness for a low concentration plume	No, due to lack of its effectiveness for a low concentration plume
		In-situ Chemical Oxidation (ISCO)	ISCO involves the injection of chemical oxidants (e.g., hydrogen peroxide, Fenton's reagent and/or persulfate) into the subsurface to destroy organic contaminants in groundwater. Complete oxidation of contaminants results in their breakdown into non-toxic compounds, such as carbon dioxide, water, and minerals. The radicals have extremely short lives and need to be generated in the subsurface where the contaminants are located. Therefore, repeat application of oxidant is generally required.	Capable of reducing contaminant mass in high concentration plumes and thereby protects human receptors. Not effective for application in low concentration plumes such as at the Site. Effective contaminant destruction if adequate contact between reagents and contaminants occurs (i.e., adequate quantity of oxidant distributed and in contact with contaminants long enough for oxidation to occur). Another limitation on effectiveness is the limited lifespan of the oxidizing agent. Can interfere with anaerobic degradation processes.	Relatively easy to implement using readily available equipment, however a treatability study and pilot scale testing may be required. Chemical delivery can be challenging in heterogeneous formations. Since the groundwater at the Site is a source of potable water, administrative difficulties can be anticipated, including meeting substantive requirements of applicable injection permits for reagents. Width, depth, and length of the low concentration plume combined with the low life span of oxidant would likely require a high density of injection points, a large quantity of oxidant, and multiple injection rounds.	High capital costs. Low O&M costs.	No, due to administrative difficulties, low concentrations, no identified source and uncertainty in effectiveness. Not cost-effective for low concentrations.	No, due to administrative difficulties, low concentrations, no identified source and uncertainty in effectiveness. Not cost-effective for low concentrations.	No, due to administrative difficulties, low concentrations, no identified source and uncertainty in effectiveness. Not cost-effective for low concentrations.
		In-situ Bioremediation	Involves injection of amendments to stimulate the anaerobic degradation pocess. Bioremediation amendments include both amendments that pimarily stimulate biotic reactions, such as source of electron donors (e.g. whey, lactate, emulsified oil) and those that also stimulate biotic/abiotic reactions such as ZVI alone and in combination with biotic amendments (e.g EHC®).	Protects human receptors by eliminating exposure to contaminants and reducing concentrations of contaminants in groundwater. Overall natural geochemistry of the cis-1,2-DCE plume has been found to be favorable for reductive dechlorination. The 1,1-DCE plume shows evidence of anoxic denitrifying conditions, which by itself may be insufficient to support further degradation of 1,1-DCE. Introduction of a suitable electron donor would create reducing conditions across the entire area thereby enhancing reductive dechlorination in the two plumes. VC is more commonly remediated using aerobic mechanisms than anaerobic.	Relatively easy to implement using readily available equipment. Remedial delivery can be challenging in heterogeneous formations. Limitations include: delivery method for nutrients, presence of nutrients in subsurface, carbon source, and type of microorganisms present in subsurface. Microcosm study and pilot-scale testing will be required.	Medium capital costs. Low O&M costs.	Yes	No, due to lack of its effectiveness for a low concentration plume	No, due to lack of its effectiveness for a low concentration plume

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Groundwater Technology Screening
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General Response Action	Remedial Technology	Process Option	Description of Response Action	Effectiveness	Technical Implementability	Relative Cost	Retained for cis-1,2-DCE Plume	Retained for PCE Plume	Retained for 1,1-DCE Plume
Discharge	On-Site Discharge	On-Site Injection	Injecting treated groundwater to the subsurface using a series of wells. Injection requires that the groundwater be treated to meet applicable groundwater standards prior to disposal to the subsurface.	The effectiveness of this option would rely on proper injection well design and construction, including adequate pipe sizing, proper placement of the wells, and reliable construction materials.	Easily implementable using available construction resources and equipment. Some implementability problems could arise during long-term operation of injection wells, such as clogging of screen packs with precipitates or microbial fouling, particularly in high iron conditions. Discharge of treated effluent may be required to meet substantive requirements of EPA UIC permit and the PRWQS.	Medium capital costs. Medium O&M costs if well rehabilitation needs to be performed periodically.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.
		Surface Water Discharge	Treated groundwater can be discharged to a surface water body such as a nearby pond or stream. Disposal to an off-Site surface water body would require that the extracted groundwater be treated to meet applicable surface water discharge standards.	Discharge to an off-Site surface water body would be an effective method for disposal of treated groundwater, depending on the distance from the treatment system to the stream. Discharge to a surface water body such as the Rio Maunabo would be an effective method for disposal of treated groundwater.	Easily implementable using available construction resources. Would be required to meet substantive requirements of NPDES permit and PRWQS for discharge.	Low capital and O&M costs.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.
	Off-Site Discharge	Discharge to POTW	Discharge of treated groundwater or treatment waste residuals to a POTW facility via a sanitary sewer. PRASA's wastewater treatment facility is located close to Maunabo #1.	Effective if there are sanitary sewers in the vicinity of the Site and treated water meets wastewater treatment facility requirements and intake capacity.	Discharge to sanitary sewers would be implementable using available construction resources if sanitary system is present near the Site. Discharged water may require pre-treatment to meet the facility acceptance requirements. Discharge technology must be combined with extraction and ex-situ treatment.	Low capital costs. Medium O&M costs.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.	No, since groundwater extraction is not retained.

Note:
Highlighted rows indicate technology eliminated from further evaluation; however technologies can be reconsidered during the FS if additional information suggest potential applicability as part of a remedial alternative.

Legend:
PREQB - Puerto Rico Environmental Quality Board
PRWQS - Puerto Rico Water Quality Standards
CSM - conceptual site model
POTW - publicly owned treatment works
UIC - underground injection control
NAPL - non aqueous phase liquid
PRG - preliminary remediation goal
SVE - soil vapor extraction
PCE - tetrachloroethene
cis-1,2-DCE - cis-1,2-dichloroethene
1,1-DCE - 1,1-dichloroethene
VC - vinyl chloride
°F - degree Fahrenheit
°C - degree celsius
bgs - below ground surface
EPA - United States Environmental Protection Agency
NPDES - National Pollutant Discharge Elimination System
PRASA - Puerto Rico Aqueduct and Sewer Authority

Table 3-1
List of Proposed Alternatives
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Alternative	PCE plume	cis-1,2-DCE plume	1,1-DCE plume
Alternative 1	No Action	No Action	No Action
Alternative 2	MNA	MNA	MNA
Alternative 3	MNA	Air sparging / Soil Vapor Extraction	MNA
Alternative 4	MNA	In-situ Bioremediation	MNA

Acronyms:
MNA - monitored natural attenuation
PCE - tetrachloroethene
cis-1,2-DCE - cis-1,2-dichloroethene
1,1-DCE - 1,1-dichloroethene

Notes:
Institutional controls, pre-design investigation, and long-term monitoring will be common to Alternatives 2, 3, 4

Table 4-1
Summary of Comparative Analysis of Remedial Action Alternatives
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

EVALUATION CRITERION	ALTERNATIVE 1 No Action	ALTERNATIVE 2 Monitored Natural Attenuation (all three plumes)	ALTERNATIVE 3 Air Sparging/Soil Vapor Extraction (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)	ALTERNATIVE 4 In-situ Bioremediation (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)
Summary of Components	None	■ Pre-design Investigation/ MNA study ■ Institutional Controls and Long-term Monitoring ■ Five-year Review	■ Pre-Design Investigation/ MNA study ■ Pilot Study ■ Air sparging/SVE of cis-1,2-DCE plume ■ Institutional Controls and Long-term Monitoring ■ Five-year Review	■ Pre-Design Investigation/ MNA study ■ Microcosm and Pilot Study ■ In-situ Bioremediation of cis-1,2-DCE plume ■ Institutional Controls and Long-term Monitoring ■ Five-year Review
Overall Protection of Human Health and the Environment	The No Action alternative would not protect human health or the environment, since no action would be taken. This alternative would not meet the RAOs.	Risk associated with contaminated groundwater in the cis-1,2-DCE and 1,1-DCE plumes may be adequately addressed through natural attenuation (biodegradation). Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. Risk associated with contaminated groundwater in the low-concentration PCE plume would be adequately addressed through natural attenuation (dilution and dispersion). Institutional controls would eliminate potential exposure pathways to receptors. If contaminant levels do not decrease to below the PRGs within a reasonable timeframe, a contingency remedy such as the more active technologies of Alternatives 3 and 4 would need to be implemented. This alternative would meet the RAOs.	Institutional controls would eliminate potential exposure pathways to receptors. This alternative would provide protection of human health and the environment. Remediation of the cis-1,2-DCE plume would significantly reduce groundwater contamination in the treatment area using air sparging. Any residual contamination would gradually reduce in concentration through natural attenuation (biodegradation). Risk associated with contaminated groundwater in the 1,1-DCE and PCE plume would be adequately addressed through natural attenuation (biodegradation, dilution and dispersion). Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. Institutional controls would eliminate potential exposure pathways to receptors. This alternative would meet the RAOs.	This alternative would provide protection of human health since institutional controls would be implemented to eliminate exposure pathways to Site contaminants. The alternative would also provide protection to the environment. Remediation of the cis-1,2-DCE plume would significantly reduce groundwater contamination in the treatment area using in-situ bioremediation. Any residual contamination in all three plumes would gradually reduce in concentration through natural attenuation processes, including degradation, dilution, and dispersion. Long-term monitoring would assess the changes in contaminant concentrations over time. This alternative would meet the RAOs.
Compliance with ARARs	This alternative would not achieve chemical-specific ARARs since no action would be taken. Action and location-specific ARARs are not applicable.	Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. Does not meet chemical-specific ARARs in the short term, although existing contaminant concentrations may decrease to acceptable levels within a reasonable timeframe. If not, a contingency remedy would need to be implemented in order to meet chemical-specific ARARs. This alternative would follow health and safety requirements to meet the action-specific ARARs. There are no location-specific ARARs for this Site.	Air sparging would meet chemical-specific ARARs by significantly reducing the contaminant concentrations in the cis-1,2-DCE plume. The residual contamination in all three plumes would gradually reduce to meet PRGs through natural attenuation processes within a reasonable timeframe. This alternative would follow health and safety requirements and permit requirements to meet the action-specific ARARs. There are no location-specific ARARs for this Site.	This alternative would meet chemical-specific ARARs by significantly reducing contaminant concentrations in the treatment area in the cis-1,2-DCE plume. The residual contamination in all three plumes would gradually reduce to meet PRGs through natural attenuation processes within a reasonable timeframe. This alternative would follow health and safety requirements and permit requirements to meet the action-specific ARARs. There are no location-specific ARARs for this Site.

Table 4-1
Summary of Comparative Analysis of Remedial Action Alternatives
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

EVALUATION CRITERION	ALTERNATIVE 1 No Action	ALTERNATIVE 2 Monitored Natural Attenuation (all three plumes)	ALTERNATIVE 3 Air Sparging/Soil Vapor Extraction (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)	ALTERNATIVE 4 In-situ Bioremediation (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)
Long-term Effectiveness and Permanence	This alternative would not be considered a permanent remedy, since no action would be taken to reduce the level of contamination. The level and migration of contaminants would not be monitored. The potential of exposure of contaminated groundwater to Site receptors would not be eliminated.	Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. If biodegradation is occurring and is sustainable, this alternative would have long-term effectiveness and permanence in all 3 plumes due to natural attenuation. Institutional controls would prevent the exposure of contaminated groundwater before the groundwater quality is restored. The long-term effectiveness of this alternative would be assessed through routine groundwater monitoring and five year reviews. If ARARs are not met through natural attenuation in a reasonable timeframe, implementation of a contingency remedy will be needed.	This alternative would have long-term effectiveness and permanence in cis-1,2-DCE plume due to air sparging and in the PCE and 1,1-DCE plumes due to natural attenuation. Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. Institutional controls would prevent exposure to contaminated groundwater while groundwater quality is restored via natural attenuation processes. The long-term effectiveness of this alternative would be assessed through routine groundwater monitoring and five year reviews.	This alternative would significantly reduce contaminant concentrations in the treatment areas. The long-term effectiveness of this alternative in the cis-1,2-DCE plume would largely rely on the effectiveness of in-situ bioremediation. Additionally, natural attenuation processes would reduce any residual contamination to meet PRGs in all three plumes. Institutional controls would prevent exposure to contaminated groundwater while groundwater quality is restored via in-situ bioremediation and natural attenuation processes. The long-term effectiveness of this alternative would be assessed through routine groundwater monitoring and five year reviews.
Reduction of Toxicity/ Mobility/Volume (T/M/V) Through Treatment	No reduction of contaminant T/M/V through treatment would be achieved under this alternative, since no action would be taken.	Unless a contingency remedy is implemented, Alternative 2 does not include an active treatment to reduce T/M/V of COCs in groundwater, however, toxicity in the plumes would be reduced through naturally occurring destructive and non-destructive mechanisms. Testing is required to show that MNA is sufficient to reduce toxicity and volume in the cis-1,2-DCE and 1,1-DCE plumes.	Air sparging would reduce the T/M/V of contamination in the cis-1,2-DCE plume. The volume and toxicity of contaminated groundwater would be reduced by the stripping of contamination from groundwater and soil. In the 1,1-DCE plume, mobility would not be reduced. However, toxicity and volume will potentially be reduced by biodegradation. T/M/V would not be reduced in the PCE plume since the mechanisms of natural attenuation would be dilution and dispersion, and not biodegradation.	In-situ bioremediation would significantly reduce the toxicity and volume of contamination in the cis-1,2-DCE plume. Chlorinated VOCs would be biotransformed to ethene and ethane. In the 1,1-DCE plume, mobility would not be reduced. However, toxicity and volume will potentially be reduced by biodegradation. T/M/V would not be reduced in the PCE plume since the mechanisms of natural attenuation would be dilution and dispersion, and not biodegradation.

Table 4-1
Summary of Comparative Analysis of Remedial Action Alternatives
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

EVALUATION CRITERION	ALTERNATIVE 1 No Action	ALTERNATIVE 2 Monitored Natural Attenuation (all three plumes)	ALTERNATIVE 3 Air Sparging/Soil Vapor Extraction (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)	ALTERNATIVE 4 In-situ Bioremediation (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)
Short-term Effectiveness	Since no remedial action would be implemented at the Site, this alternative would not have any short-term impact. The No Action alternative would not have adverse environmental impacts to habitat or vegetation at the Site since no action would be taken.	For long-term monitoring to be conducted on private property, coordination and access would need to be obtained from private property owners. Level D personal protective equipment (PPE) is required during sampling. Short-term protection afforded to community through institutional controls. Protection of Maunabo #1 is dependent upon rate and presence of natural attenuation parameters.	This alternative would have some short-term impacts to the community and the environment. AS/SVE would need to be installed and operated on the Site for approximately three years. Installation of the system would be performed without significant risk to the community. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards. AS/SVE will be effective in the short term. VC and cis-1,2-DCE are volatile compounds that can be stripped relatively effectively from groundwater with sparging. The aerobic conditions in the groundwater created by the sparge system will induce a degree of biodegradation of the contaminants. Implementing MNA in the PCE plume and 1,1-DCE plume would not be effective in the short term, since effectiveness would rely upon the dilution and dispersion created by groundwater flow and naturally occurring biodegradation to reduce concentrations to the PRG.	The EHC® could be injected as a bio-barrier in the vicinity of MW-I and south of the perimeter of the PRB facility inward to minimize contaminant migration caused by displacement. This alternative would have some short-term impacts to the community and the environment. Amendment injections would likely be completed in one month. Installation of injections would be performed without significant risk to the community. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards. Implementing MNA in the PCE plume and 1,1-DCE plume would not be effective in the short term, since effectiveness would rely upon the dilution and dispersion created by groundwater flow and naturally occurring biodegradation to reduce concentrations to the PRG.

Table 4-1
Summary of Comparative Analysis of Remedial Action Alternatives
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

EVALUATION CRITERION	ALTERNATIVE 1 No Action	ALTERNATIVE 2 Monitored Natural Attenuation (all three plumes)	ALTERNATIVE 3 Air Sparging/Soil Vapor Extraction (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)	ALTERNATIVE 4 In-situ Bioremediation (cis-1,2-DCE plume) and Monitored Natural Attenuation (PCE and 1,1-DCE plumes)
Implementability	This alternative would be easy to implement since no action would be taken.	This alternative is implementable. Additional data collection is required in the cis-1,2-DCE and 1,1-DCE plumes to confirm biodegradation. Services and materials are readily available. No problems are anticipated for the implementation and enforcement of the institutional controls. Access agreements would be required to implement this alternative on private property.	This alternative is implementable. MNA, AS/SVE are well established technologies and could be readily implemented at the Site. This alternative would require the use of readily available conventional construction and subsurface drilling equipment. Groundwater monitoring associated with MNA would be easily implementable using readily available services and materials.	This alternative is implementable. A microcosm and pilot study would be implemented to obtain Site-specific information for the full scale remediation. Administrative difficulties can be anticipated from the Commonwealth of Puerto Rico to get approval on injecting bio-amendments in the waters of Puerto Rico. Services and materials for implementation of this alternative are readily available. Competitive bids would be obtained from a number of equipment vendors and remediation contractors. No problems are anticipated for the implementation and enforcement of the institutional controls. Access agreements would be required to implement this alternative on private property.
Estimated Time for Implementation	<1year	30 years	3 years for AS/SVE in cis-1,2-DCE plume and 30 years assumed for MNA	2 years for in-situ bioremediation in cis-1,2-DCE plume and 30 years assumed for MNA
Total Present Worth Costs	$0	$2.5 million	$4.8 million	$4.5 million

Acronyms:
cis-1,2-DCE – cis-1,2-dichloroethene
1,1-DCE – 1,1-dichloroethene
PCE – tetrachloroethene
VC – vinyl chloride
MNA – monitored natural attenuation
RAO – Remedial Action Objective
COC – contaminant of concern
ARAR – Applicable or Relevant and Appropriate Requirements
TBD – to be decided
AS – air sparging
SVE – soil vapor extraction
< - less than

Table 4-2
Summary of Capital, Operation and Maintenance, and Present Worth Costs
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

EVALUATION CRITERION	ALTERNATIVE 1 No Action	ALTERNATIVE 2 MNA (all three plumes)	ALTERNATIVE 3 AS/SVE (cis-1,2-DCE) and MNA (PCE and 1,1-DCE)	ALTERNATIVE 4 In-situ Bioremediation (cis-1,2-DCE) and MNA (PCE and 1,1-DCE)
Capital Costs	$0	$369,928	$2,104,400	$2,401,681
Annual O&M Cost	$0	$0	One Year: $268,734 Annual for 5 Years: $79,300	$0
Annual LTM Cost Quarterly Years 1 & 2 Annually Years 3 to 30	$0	Qtr: $103,000 Ann: $126,000	Qtr: $103,000 Ann: $126,000	Qtr: $103,000 Ann: $126,000
Present Worth O&M Costs[1]	$0	$2,098,449	$2,692,329	$2,098,449
Total Present Worth Costs	$0	$2,500,000	$4,800,000	$4,500,000

Notes:

1. Present worth calculation assumes 7% interest after inflation is considered

Acronyms:

AS - air sparging

SVE - soil vapor extraction

MNA - Monitored Natural Attenuation

O&M - Operations and Maintenance

Figures

R2-0002464

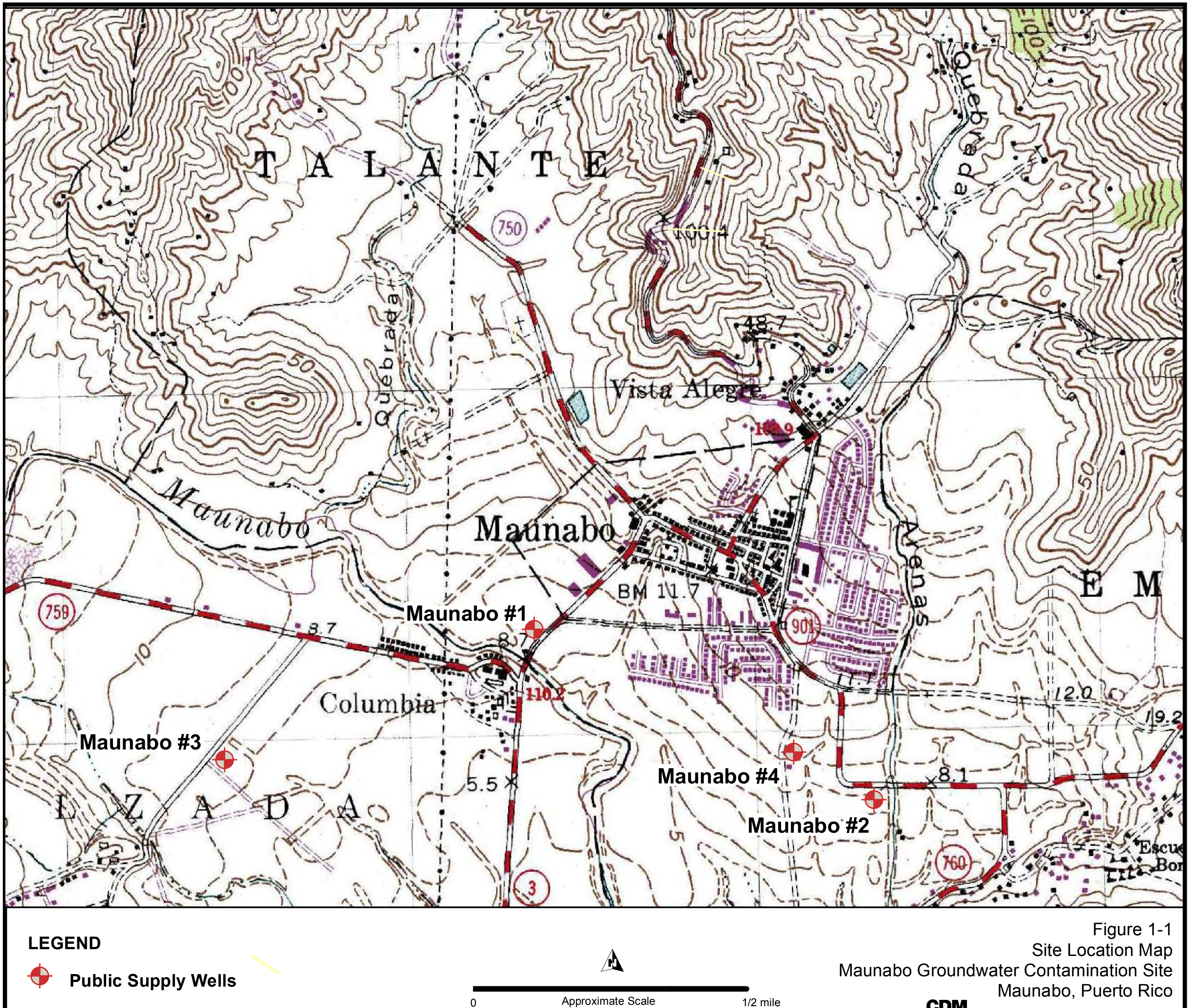
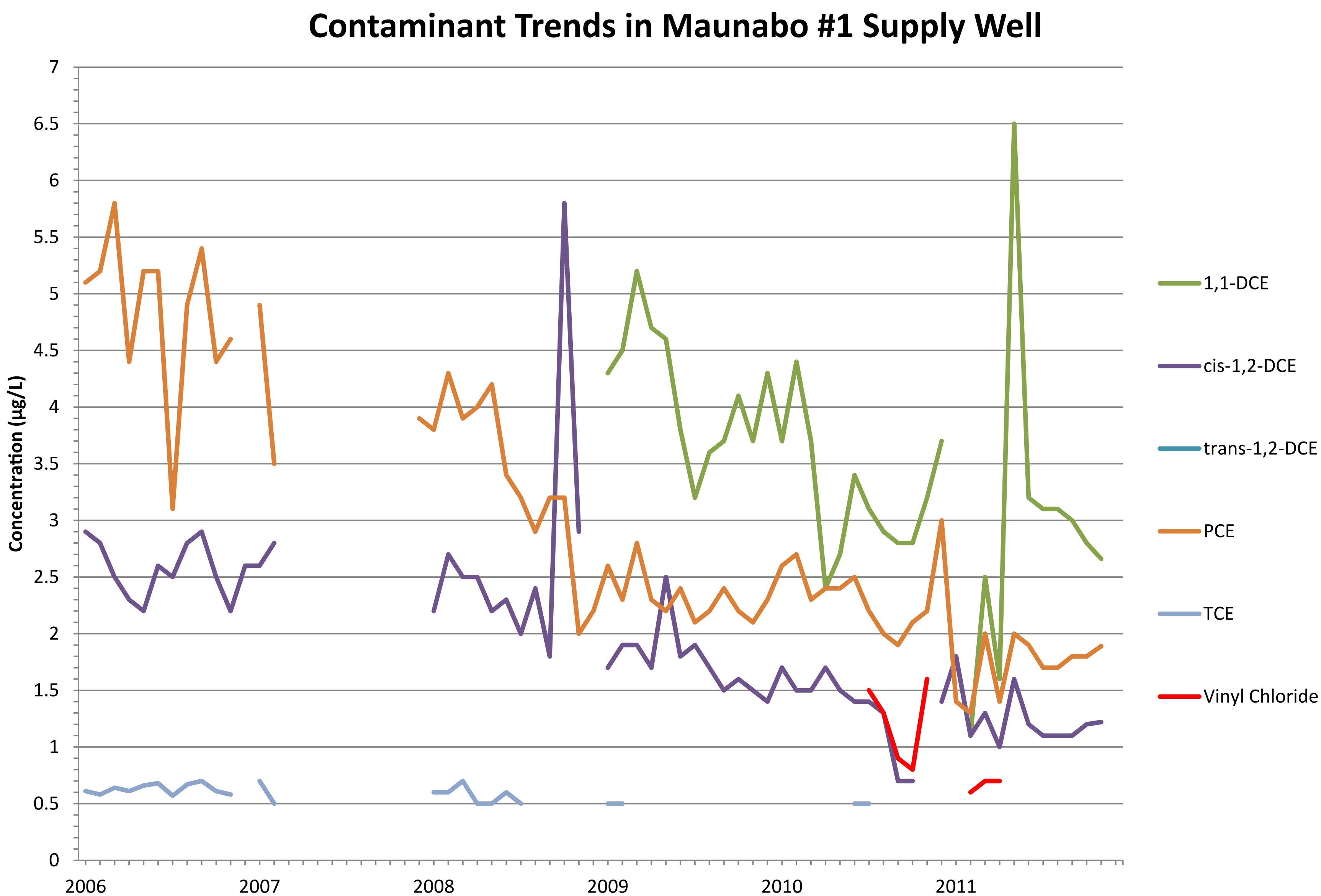


Figure 1-1
Site Location Map
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

R2-0002465



CDM Smith

FIgure 1-2
Contaminant Trends in Maunabo #1 Supply Well
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

R2-0002466

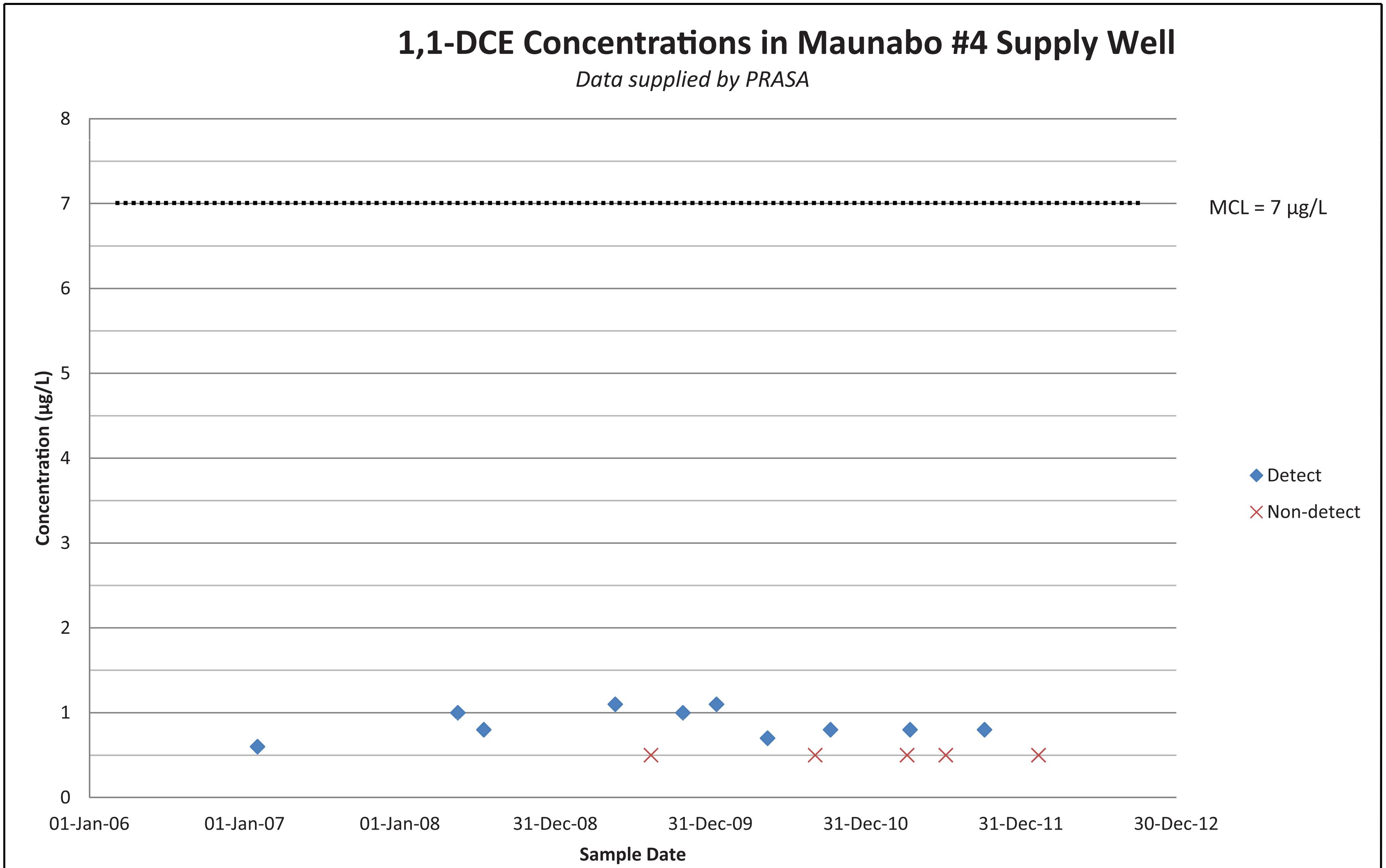
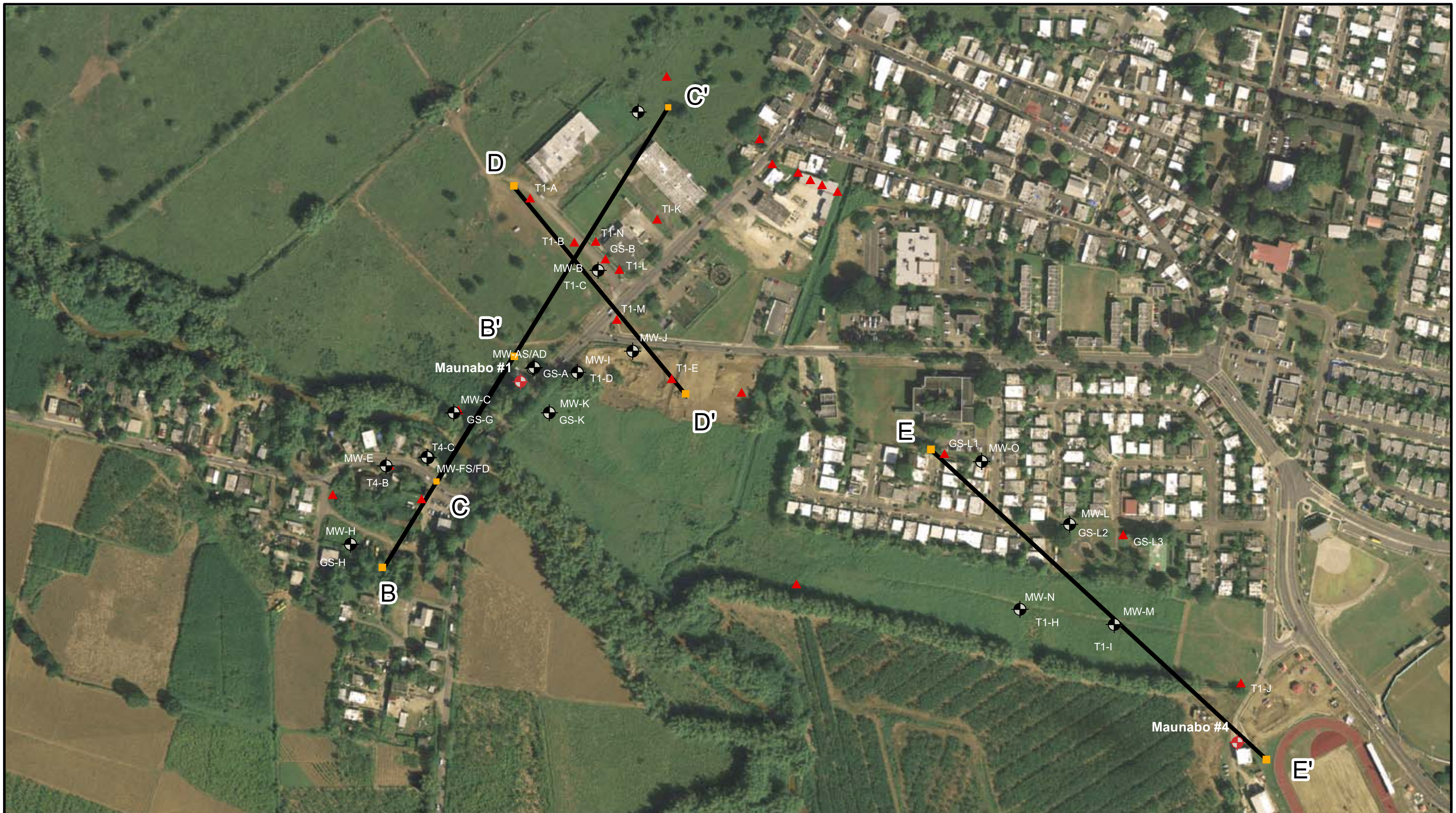


Figure 1-3
1,1-DCE Concentrations in Maunabo #4 Supply Well
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith



Legend

- Public Supply Well Location
- Monitoring Well Location
- Groundwater Screening Location
- Cross Section Line

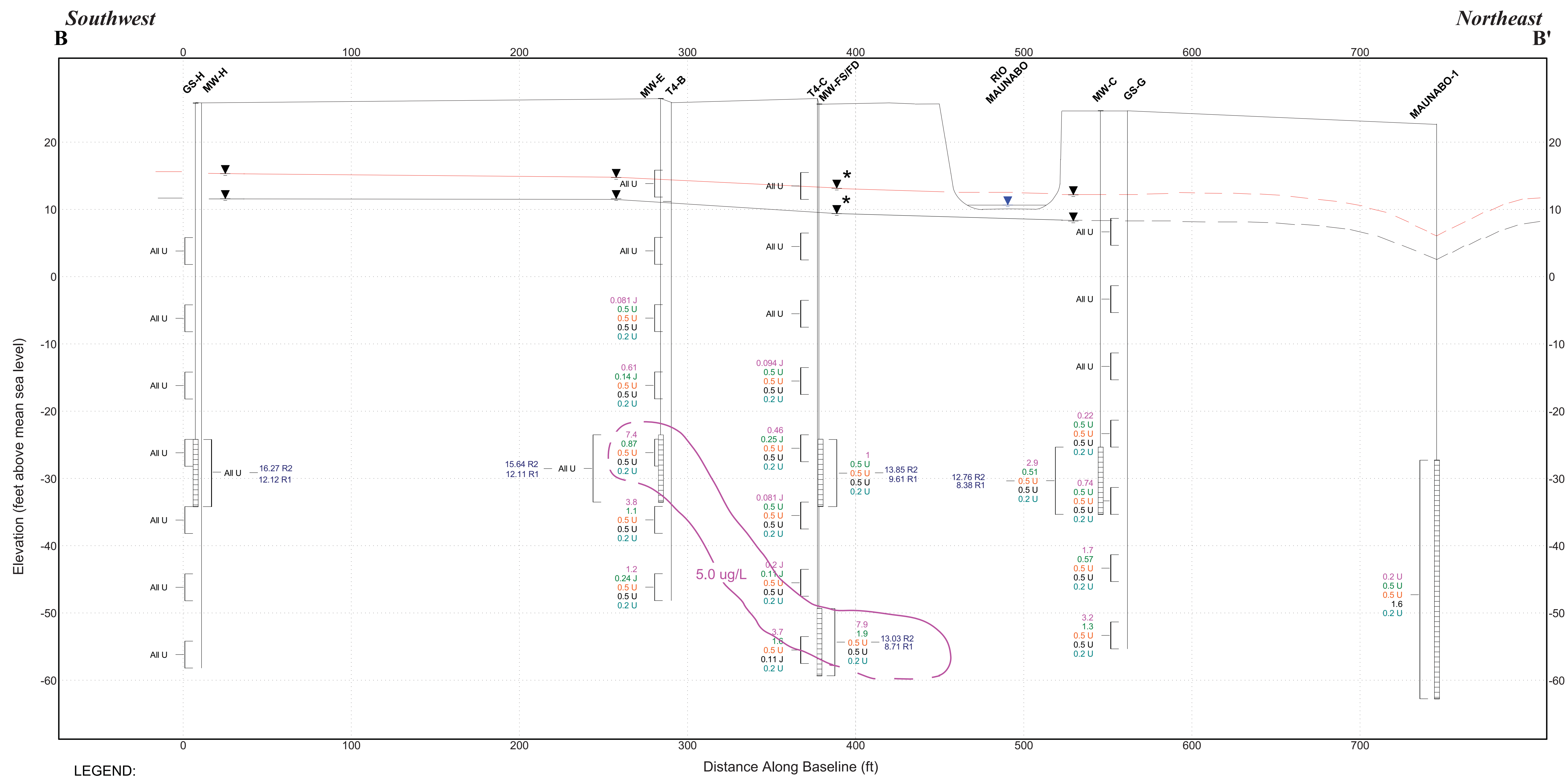
0 160 320 640 960 1,280 Feet

All elevations are expressed in feet sbove mean sea level (ft amsl)

Figure 1-4
Cross Section Location Map
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

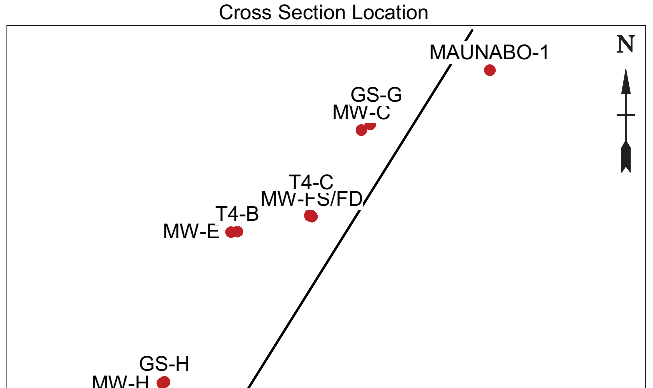
CDM Smith

R2-0002468



LEGEND:

Cross Section Location



Site Map Scale 1 inch equals 305 feet

Tetrachloroethene isoconcentration
* Indicates water level from shallow well of cluster used for potentiometric surface.
Potentiometric surface (dashed where inferred)
Black = Round 1 (March, 2011)
Orange = Round 2 (June, 2011)
Water level elevation in river
Approximate ground surface elevation
Screened Interval

Water Level Elevation 8.38
(feet above mean sea level)

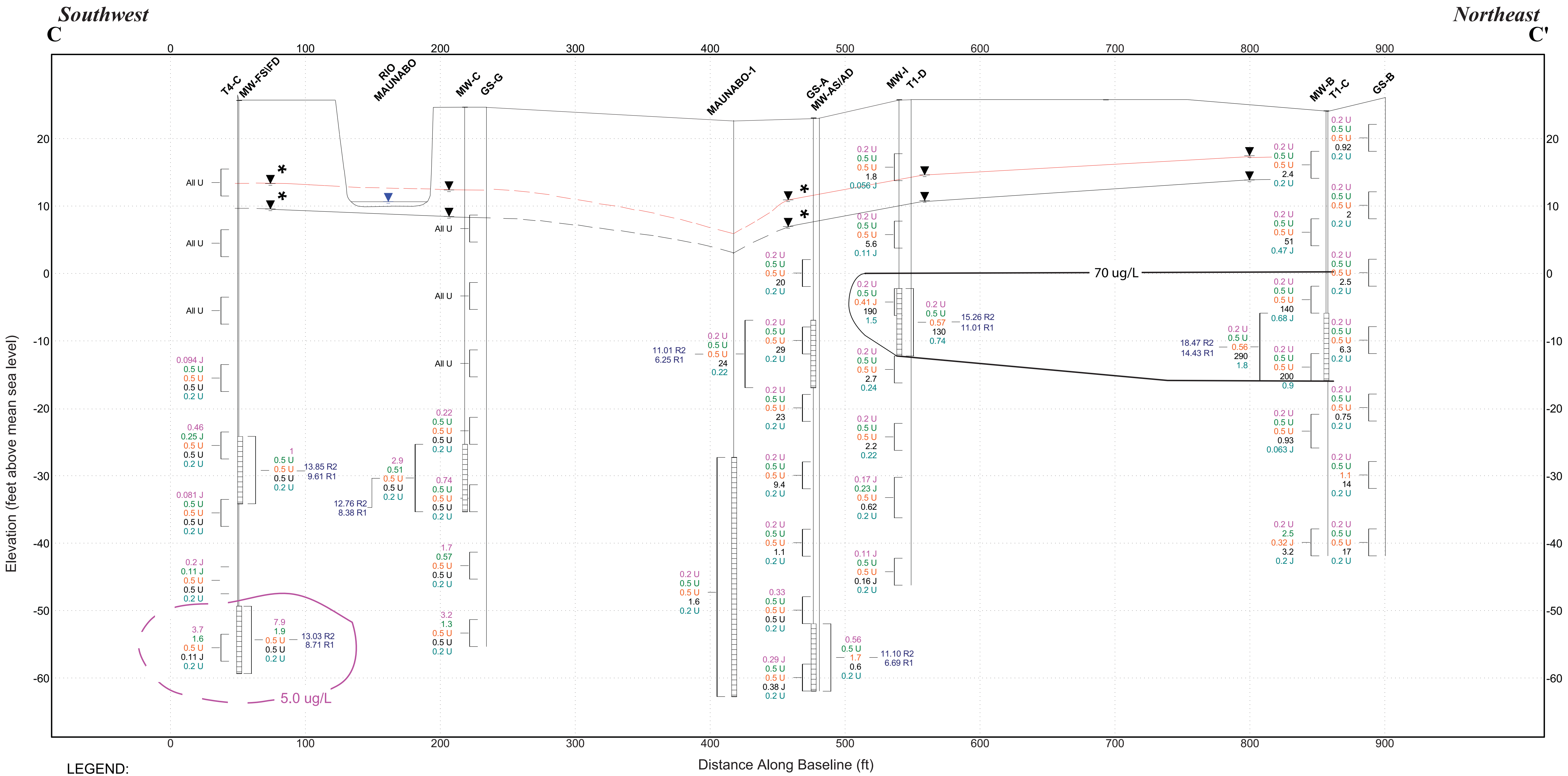
Groundwater Sample Results
Tetrachloroethene (PCE)
Trichloroethene (TCE)
1,1-Dichloroethene (1,1-DCE)
cis-1,2-Dichloroethene
Vinyl Chloride
All results in micrograms per liter
U - not detected, detection limit is value to left
J - estimated concentration
All U - all analytes were not detected

Figure 1-5
Site Related Contaminants
Cross Section B-B'
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

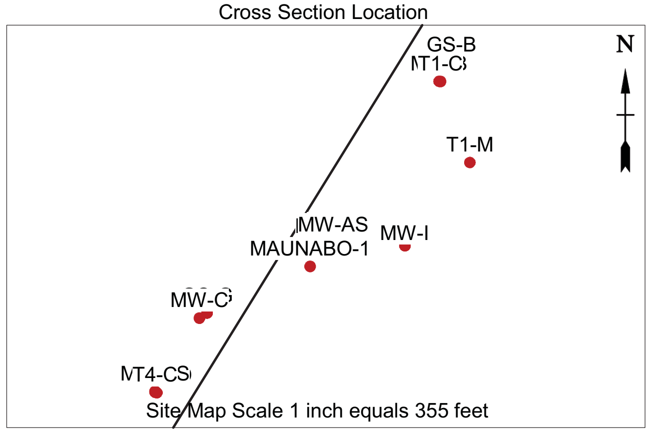
STANDARD CROSS SECTION: MAUNABO MAUNABO_GROUNDWATER.GPJ STANDARD_ENVIRONMENTAL_PROJECT.GDT 11/1/11 REV.

R2-0002469



LEGEND:

Cross Section Location



Tetrachloroethene isoconcentration

cis-1,2-Dichloroethene isoconcentration

* Indicates water level from shallow well of cluster used for potentiometric surface.

Potentiometric surface (dashed where inferred)
Black = Round 1 (March, 2011)
Orange = Round 2 (June, 2011)

Water level elevation in river

Approximate ground surface elevation

Screened Interval

Water Level Elevation 14.93
(feet above mean sea level)

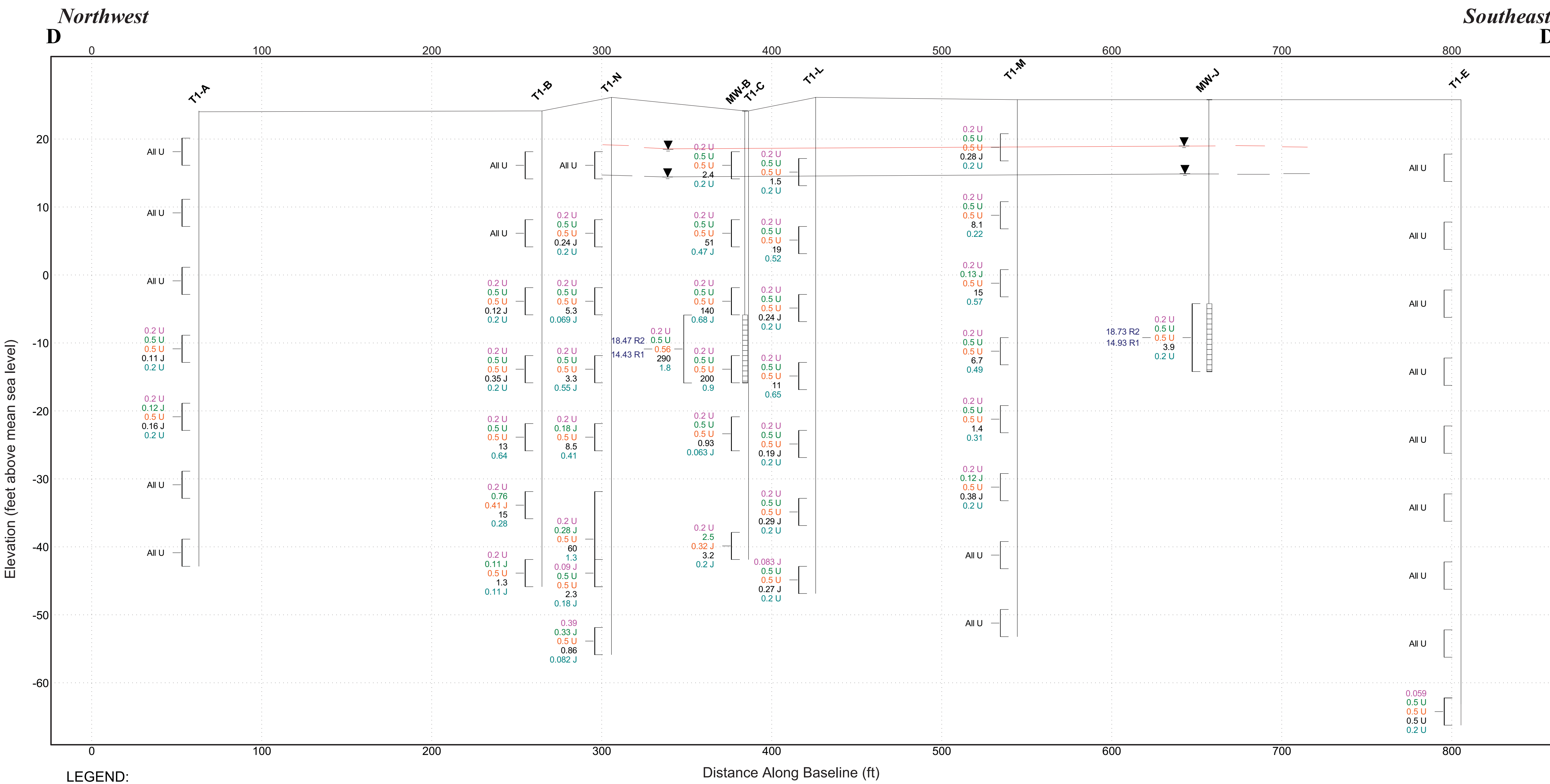
Groundwater Sample Results
Tetrachloroethene (PCE)
Trichloroethene (TCE)
1,1-Dichloroethene (1,1-DCE)
cis-1,2-Dichloroethene
Vinyl Chloride
All results in micrograms per liter
U - not detected, detection limit is value to left
J - estimated concentration
All U - all analytes were not detected

Figure 1-6
Site Related Contaminants
Cross Section C-C'
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

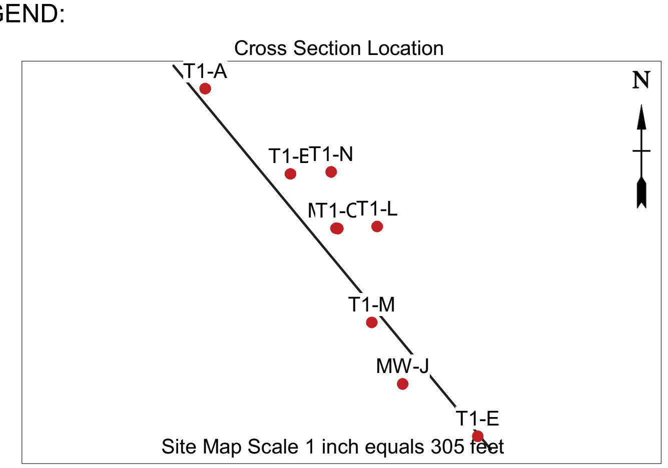
CDM Smith

STANDARD CROSS SECTION: MAUNABO MAUNABO_GROUNDWATER.GPJ STANDARD_ENVIRONMENTAL_PROJECT.GDT 11/10/11 REV.

R2-0002470



LEGEND:



Potentiometric surface (dashed where inferred)
Black = Round 1 (March, 2011)
Orange = Round 2 (June, 2011)

Approximate ground surface elevation

Screened Interval

Water Level Elevation 14.93
(feet above mean sea level)
Date: March 14, 2011

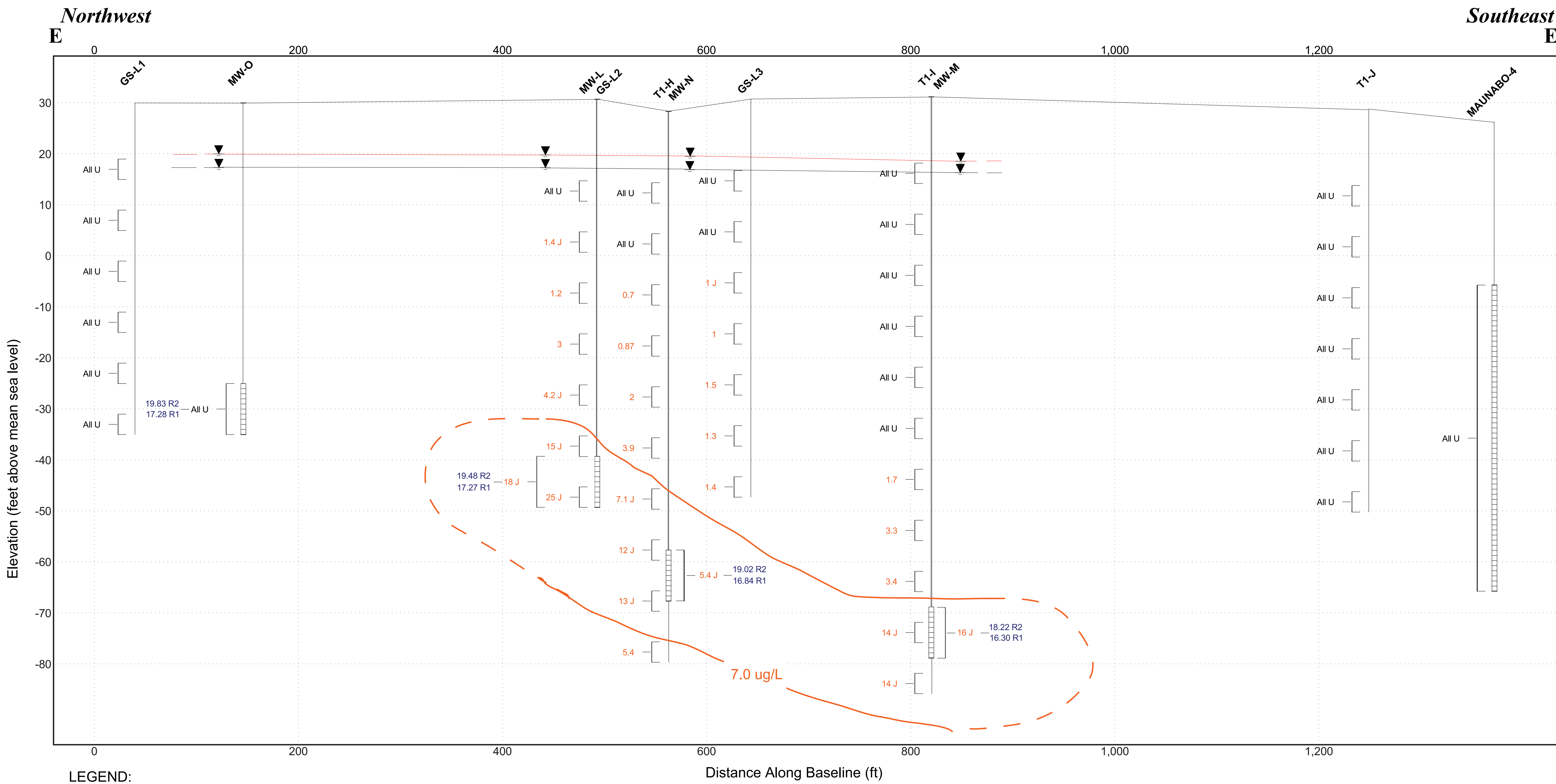
Groundwater Sample Results
Tetrachloroethene (PCE)
Trichloroethene (TCE)
1,1-Dichloroethene (1,1-DCE)
cis-1,2-Dichloroethene
Vinyl Chloride
All results in micrograms per liter
U - not detected, detection limit is value to left
J - estimated concentration
All U - all analytes were not detected

Figure 1-7
Site Related Contaminants
Cross Section D-D'
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

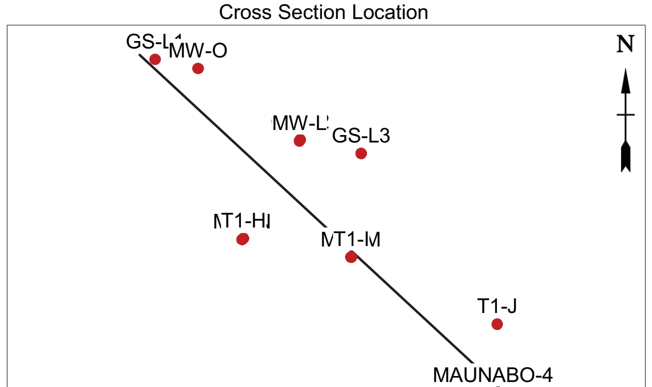
STANDARD CROSS SECTION: MAUNABO MAUNABO_GROUNDWATER.GPJ STANDARD_ENVIRONMENTAL_PROJECT.GDT 11/10/11 REV.

R2-0002471



LEGEND:

Cross Section Location



Site Map Scale 1 inch equals 510 feet

Note: Site related contaminants tetrachloroethene (PCE), trichloroethene (TCE), cis 1,2-dichloroethene (1,2-DCE) and vynil chloride were non detect.

1,1-Dichloroethene isoconcentration

Potentiometric surface (dashed where inferred)
Black = Round 1 (March, 2011)
Orange = Round 2 (June, 2011)

Approximate ground surface elevation

Screened Interval

Water Level Elevation 16.30
(feet above mean sea level)
Date: March 14, 2011

Groundwater Sample Results
1,1-Dichloroethene (1,1-DCE)
All results in micrograms per liter
U - not detected, detection limit is value to left
J - estimated concentration
All U - all analytes were not detected

Figure 1-8
Site Related Contaminants
Cross Section E-E'
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

STANDARD CROSS SECTION: MAUNABO MAUNABO_GROUNDWATER.GPJ STANDARD_ENVIRONMENTAL_PROJECT.GDT 11/10/11 REV.

R2-0002472

T1-N					
Sample Depth (feet bgs)	PCE	TCE	cis- 1,2 DCE	trans-1,2 DCE	Vinyl chloride
8-12	0.2 U	0.5 U	0.5 U	0.5 U	0.2 U
18-22	0.2 U	0.5 U	**0.24 J**	0.5 U	0.2 U
28-32	0.2 U	0.5 U	**5.3**	0.5 U	**0.069 J**
38-42	0.2 U	0.5 U	**3.3**	0.5 U	**0.055 J**
48-52	0.2 U	**0.18 J**	**8.5**	**0.17 J**	**0.41**
58-72	0.2 U	**0.28 J**	**60**	**1.2**	**1.3**
68-72	**0.09 J**	0.5 U	**2.3**	0.5 U	**0.18 J**
78-82	**0.39**	**0.33 J**	**0.86**	0.5 U	**0.082 J**
78-82 Dup	**0.2 J**	**0.29 J**	**0.81**	0.5 U	**0.056 J**

T1-A		
Sample Depth (feet bgs)	TCE	cis- 1,2 DCE
4-8	0.5 U	0.5 U
13-17	0.5 U	0.5 U
23-27	0.5 U	0.5 U
33-37	0.5 U	**0.11**
43-47	**0.12**	**0.16**
53-57	0.5 U	0.5 U
63-67	0.5 U	0.5 U

GS-B			
Sample Depth (feet bgs)	cis- 1,2 DCE	1,1 - DCE	trans-1,2 DCE
4-8	**0.92**	0.5 U	0.5 U
14-18	**2**	0.5 U	0.5 U
24-28	**2.5**	0.5 U	0.5 U
34-38	**6.3**	0.5 U	0.5 U
44-48	**0.75**	0.5 U	0.5 U
54-58	**14**	**1.1**	0.5 U
64-68	**17**	0.5 U	**0.44 J**

T1-B					
Sample Depth (feet bgs)	TCE	cis- 1,2 DCE	1,1 - DCE	trans-1,2 DCE	Vinyl chloride
6-10	0.5 U	0.5 U	0.5 U	0.5 U	0.2 U
16-20	0.5 U	**0.12 J**	0.5 U	0.5 U	0.2 U
26-30	0.5 U	**0.12 J**	0.5 U	0.5 U	0.2 U
36-40	0.5 U	**0.35 J**	0.5 U	0.5 U	0.2 U
46-50	0.5 U	**13**	0.5 U	**0.19 J**	**0.64**
56-60	**0.76**	**15**	**0.41 J**	**0.18 J**	**0.28**
66-70	**0.11 J**	**1.3**	0.5 U	0.5 U	**0.11 J**

T1-L				
Sample Depth (feet bgs)	PCE	cis- 1,2 DCE	trans-1,2 DCE	Vinyl chloride
9-13	0.2 U	**1.5**	0.5 U	0.2 U
19-23	0.2 U	**19**	**0.59**	**0.52**
29-33	0.2 U	**11**	**0.74**	**0.65**
39-43	0.2 U	**0.24 J**	0.5 U	0.2 U
49-56	0.2 U	**0.19 J**	0.5 U	0.2 U
59-63	0.2 U	**0.29 J**	0.5 U	0.2 U
69-73	**0.083 J**	**0.27 J**	0.5 U	0.2 U

GSA				
Sample Depth (feet bgs)	PCE	cis- 1,2 DCE	trans-1,2 DCE	Vinyl chloride
21-25	0.2 U	**20**	0.5 U	0.2 U
31-35	0.2 U	**29**	0.5 U	0.2 U
41-45	0.2 U	**23**	0.5 U	0.2 U
41-45 Dup	0.2 U	**19**	**0.78**	0.2 U
51-55	0.2 U	**9.4**	0.5 U	0.2 U
61-65	0.2 U	**1.1**	0.5 U	0.2 U
71-75	**0.33**	0.5 U	0.5 U	0.2 U
81-85	**0.29 J**	**0.38 J**	0.5 U	**0.5**

T1-C					
Sample Depth (feet bgs)	TCE	cis- 1,2 DCE	1,1 - DCE	trans-1,2 DCE	Vinyl chloride
6-10	0.5 U	**2.4**	0.5 U	0.5 U	0.2 U
16-20	0.5 U	**51**	0.5 U	**0.8**	**0.47 J**
26-30	0.5 U	**140**	0.5 U	**2.1**	**0.68 J**
36-40	0.5 U	**200**	0.5 U	**3.5**	**0.9**
46-50	0.5 U	**0.93**	0.5 U	0.5 U	**0.063 J**
62-66	**2.5**	**3.2**	**0.32 J**	0.5 U	**0.2 J**

T1-M				
Sample Depth (feet bgs)	TCE	cis- 1,2 DCE	trans-1,2 DCE	Vinyl chloride
5-9	0.5 U	**0.28 J**	0.5 U	0.2 U
15-19	0.5 U	**8.1**	**0.13 J**	**0.22**
25-29	**0.13 J**	**15**	**0.18 J**	**0.57**
35-39	0.5 U	**6.7**	0.5 U	**0.49**
45-49	0.5 U	**1.4**	0.5 U	**0.31**
55-59	**0.12 J**	**0.38 J**	0.5 U	0.2 U
65-69	0.5 U	0.5 U	0.5 U	0.2 U
75-79	0.5 U	0.5 U	0.5 U	0.2 U

GS-G		
Sample Depth (feet bgs)	PCE	TCE
16-20	0.2 U	0.5 U
26-30	0.2 U	0.5 U
36-40	0.2 U	0.5 U
46-50	**0.22**	0.5 U
56-60	**0.74**	0.5 U
66-70	**1.7**	**0.57**
76-80	**3.2**	**1.3**
76-80 Dup	**2.6**	**1.4**

T1-D						
Sample Depth (feet bgs)	PCE	TCE	cis- 1,2 DCE	1,1 - DCE	trans-1,2 DCE	Vinyl chloride
8-12	0.2 U	0.5 U	**1.8**	0.5 U	0.5 U	**0.056 J**
18-22	0.2 U	0.5 U	**5.6**	0.5 U	0.5 U	**0.11 J**
28-32	0.2 U	0.5 U	**190**	**0.41 J**	**0.63**	**1.5**
38-42	0.2 U	0.5 U	**2.7**	0.5 U	0.5 U	**0.24**
48-52	0.2 U	0.5 U	**2.2**	0.5 U	0.5 U	**0.22**
58-62	**0.17 J**	**0.23 J**	**0.62**	0.5 U	0.5 U	0.2 U
68-72	**0.11 J**	0.5 U	**0.16 J**	0.5 U	0.5 U	0.2 U

GS-L2	
Sample Depth (feet bgs)	1,1 - DCE
16-20	0.5 U
26-30	**1.4 J**
36-40	**1.2**
46-50	**3**
56-60	**4.2 J**
66-70	**15 J**
76-80	**25 J**

GS-L3	
Sample Depth (feet bgs)	1,1 - DCE
14-18	0.5 U
24-28	0.5 U
34-38	**1.0 J**
44-48	**1.0**
44-48 Dup	**1.0**
54-58	**1.5**
64-68	**1.3**
74-78	**1.4**

T4-B		
Sample Depth (feet bgs)	PCE	TCE
10-14	0.2 U	0.5 U
20-24	0.2 U	0.5 U
30-34	**0.081 J**	0.5 U
40-44	**0.61**	**0.14 J**
50-54	**7.4**	**0.87**
60-64	**3.8**	**1.1**
70-74	**1.2**	**0.24 J**

GS-K			
Sample Depth (feet bgs)	TCE	cis- 1,2 DCE	1,1 - DCE
16-20	0.5 U	**9.6**	0.5 U
26-30	0.5 U	**8.3**	0.5 U
36-40	0.5 U	**4.2**	0.5 U
46-50	**0.61**	**6.3**	0.5 U
56-60	0.5 U	**1.8**	**0.69**
56-60 Dup	0.5 U	0.5 U	**0.77**
66-70	0.5 U	0.5 U	**0.74**
76-80	0.5 U	0.5 U	0.5 U

T1-E	
Sample Depth (feet bgs)	PCE
8-12	0.2 U
18-22	0.2 U
28-32	0.2 U
38-42	0.2 U
48-52	0.2 U
58-62	0.2 U
68-72	0.2 U
78-82	0.2 U
88-92	**0.059**

T4-C			
Sample Depth (feet bgs)	PCE	TCE	cis- 1,2 DCE
10-14	0.2 U	0.5 U	0.5 U
20-24	0.2 U	0.5 U	0.5 U
30-34	0.2 U	0.5 U	0.5 U
40-44	**0.094 J**	0.5 U	0.5 U
50-54	**0.46**	**0.25 J**	0.5 U
60-64	**0.081 J**	0.5 U	0.5 U
70-74	**0.2 J**	**0.11 J**	0.5 U
80-84	**3.7**	**1.6**	**0.11 J**

T4-D		
Sample Depth (feet bgs)	PCE	TCE
10-14	0.2 U	0.5 U
20-24	0.2 U	0.5 U
30-34	0.2 U	0.5 U
40-44	**0.067 J**	0.5 U
50-54	**0.082 J**	0.5 U
60-64	0.2 U	0.5 U
70-74	**0.11 J**	0.5 U
80-84	**0.62**	**0.34 J**

T1-G			
Sample Depth (feet bgs)	cis- 1,2 DCE	1,1 - DCE	Vinyl chloride
4-8	0.5 U	0.5 U	0.2 U
14-18	0.5 U	0.5 U	0.2 U
24-28	0.5 U	0.5 U	0.2 U
34-38	0.5 U	0.5 U	0.2 U
44-48	**0.11 J**	**1.4**	**0.06 J**
54-58	**0.12 J**	**2.4**	**0.089 J**
64-68	0.5 U	**4**	0.2 U
74-78	0.5 U	**5.3**	0.2 U
84-88	0.5 U	**4.5**	0.2 U

T1-H	
Sample Depth (feet bgs)	1,1 - DCE
14-18	0.5 U
24-28	0.5 U
34-38	**0.7**
44-48	**0.87**
54-58	**2**
64-68	**3.9**
74-78	**7.1 J**
84-88	**12 J**
94-98	**13 J**
104-108	**5.4**

T1-I	
Sample Depth (feet bgs)	1,1 - DCE
13-17	0.5 U
23-27	0.5 U
33-37	0.5 U
43-47	0.5 U
53-57	0.5 U
63-67	0.5 U
73-77	**1.7**
83-87	**3.3**
93-97	**3.4**
103-107	**14 J**
113-117	**14 J**

Groundwater Screening Criteria for Site Related Contaminants	
VOC	Standards (µg/L)
PCE	5.0
TCE	5.0
cis-1,2 DCE	70.0
1,1 - DCE	7.0
trans-1,2 DCE	100.0
Vinyl chloride	0.25
Values that exceed screening criteria are highlighted in yellow	
Values in bold represent detections	

Legend

- Maunabo Public Wells
- Site Related Contaminants detected
- Site Related Contaminants not detected

Notes:
Detections are in bold
ft bgs - feet below ground surface
J - estimated value
µg/L - micrograms per liter
U - not detected above the listed detection limit
VOC - volatile organic compound
PCE - tetrachloroethene
TCE - trichloroethene
DCE - dichloroethene

Feet
0 160 320 640 960 1,280

Figure 1-9
Groundwater Screening Results for Site Related Contaminants
Maunabo Groundwater Contamination Site
Maunabo, PR

CDM Smith

MW-D (background)		
Event	Depth (ft bgs)	VOCs (µg/L)
Round 1	35	No SRCs Detected
Round 2	35	No SRCs Detected

MW-AS			
VOCs (µg/L)			
Event	Depth (ft bgs)	cis-1,2 DCE	Vinyl chloride
Round 1	35	**24**	**0.22**
Round 2	35	**23**	0.2 U

MW-B					
VOCs (µg/L)					
Event	Depth (ft bgs)	cis-1,2 DCE	1,1 - DCE	trans -1,2 DCE	Vinyl Chloride
Round 1	35	**290**	**0.56**	**13**	**1.8**
Round 2	35	**300**	0.5 U	**7.7**	0.2 U

MW-AD					
VOCs (µg/L)					
Event	Depth (ft bgs)	PCE	TCE	cis-1,2 DCE	1,1 - DCE
Round 1	80	**0.56**	0.5 U	**0.6**	**1.7**
Round 2	80	**7.6**	**1.6**	0.5 U	0.5 U

Maunabo 1					
VOCs (µg/L)					
Event	Depth (ft bgs)	PCE	TCE	cis-1,2 DCE	1,1 - DCE
Round 1	N/A	0.2 U	0.5 U	**1.6**	0.5 U
Round 1	N/A (Dup)	0.2 U	0.5 U	**1.5**	0.5 U
Round 2	N/A	**1.8**	**0.40 J**	**1.6**	**0.22 J**
Round 2	N/A (Dup)	**1.7**	**0.34 J**	**1.4**	**0.30 J**

MW-J		
VOCs (µg/L)		
Event	Depth (ft bgs)	cis-1,2 DCE
Round 1	33	**3.9**
Round 2	33	**3.2**

MW-C			
VOCs (µg/L)			
Event	Depth (ft bgs)	PCE	TCE
Round 1	55	**2.9**	**0.51**
Round 2	55	**1.6**	**0.42 J**

MW-I					
VOCs (µg/L)					
Event	Depth (ft bgs)	cis-1,2 DCE	1,1 - DCE	trans -1,2 DCE	Vinyl Chloride
Round 1	33	**130**	**0.57**	**0.99**	**0.74**
Round 2	33	**260**	**0.78**	**1.4**	**1.0**

MW-O (background)		
Event	Depth (ft bgs)	VOCs (µg/L)
Round 1	60	No SRCs Detected
Round 2	60	No SRCs Detected

MW-E		
Event	Depth (ft bgs)	VOCs (µg/L)
Round 1	55	No SRCs Detected
Round 2	55	No SRCs Detected

MW-K			
VOCs (µg/L)			
Event	Depth (ft bgs)	cis-1,2 DCE	Vinyl Chloride
Round 1	33	**11**	0.2 U
Round 2	33	**15**	**0.66**

MW-H (background)		
Event	Depth (ft bgs)	VOCs (µg/L)
Round 1	55	No SRCs Detected
Round 2	55	No SRCs Detected

MW-L		
VOCs (µg/L)		
Event	Depth (ft bgs)	1,1 - DCE
Round 1	75	**18 J**
Round 2	75	**25 J**

MW-FS			
VOCs (µg/L)			
Event	Depth (ft bgs)	PCE	TCE
Round 1	55	**1.0**	0.5 U
Round 2	55	**0.86**	**0.29 J**

MW-N			
VOCs (µg/L)			
Event	Depth (ft bgs)	cis-1,2 DCE	1,1 - DCE
Round 1	85	0.5 U	**5.4 J**
Round 2	85	**0.38 J**	**15 J**

MW-FD					
VOCs (µg/L)					
Event	Depth (ft bgs)	PCE	TCE	cis-1,2 DCE	1,1 - DCE
Round 1	80	**8.5 J**	**1.9**	0.5 U	0.5 U
Round 1	80 (Dup)	**7.8**	**1.8**	0.5 U	0.5 U
Round 2	80	**0.53**	0.5 U	**0.56**	**1.7**
Round 2	80 (Dup)	**7.9**	**1.8**	0.5 U	0.5 U

MW-M			
VOCs (µg/L)			
Event	Depth (ft bgs)	cis-1,2 DCE	1,1 - DCE
Round 1	105	0.5 U	**16 J**
Round 2	105	0.5 U	0.5 U

Groundwater Screening Criteria for Site Related Contaminants	
VOC	Standards (µg/L)
PCE	5.0
TCE	5.0
cis-1,2 DCE	70.0
1,1 - DCE	7.0
trans-1,2 DCE	100.0
Vinyl chloride	0.25
Values that exceed screening criteria are highlighted in yellow	
Values in bold represent detections	

Maunabo #4		
VOCs (µg/L)		
Event	Depth (ft bgs)	1,1 - DCE
Round 1	N/A	0.5 U
Round 2	N/A	**1.1**

Notes:
Detections are in bold
ft bgs - feet below ground surface
J - estimated value
µg/L - micrograms per liter
U - not detected above the listed detection limit

VOC - volatile organic compound
PCE - tetrachloroethene
TCE - trichloroethene
DCE - dichloroethene
SRC - Site Related Contaminants

N

0 150 300 600 900 1,200 Feet

Figure 1-10
Rounds 1 and 2 Monitoring Well Results for Site Related Contaminants
Maunabo Groundwater Contamination Site
Maunabo, PR

CDM Smith

R2-0002474

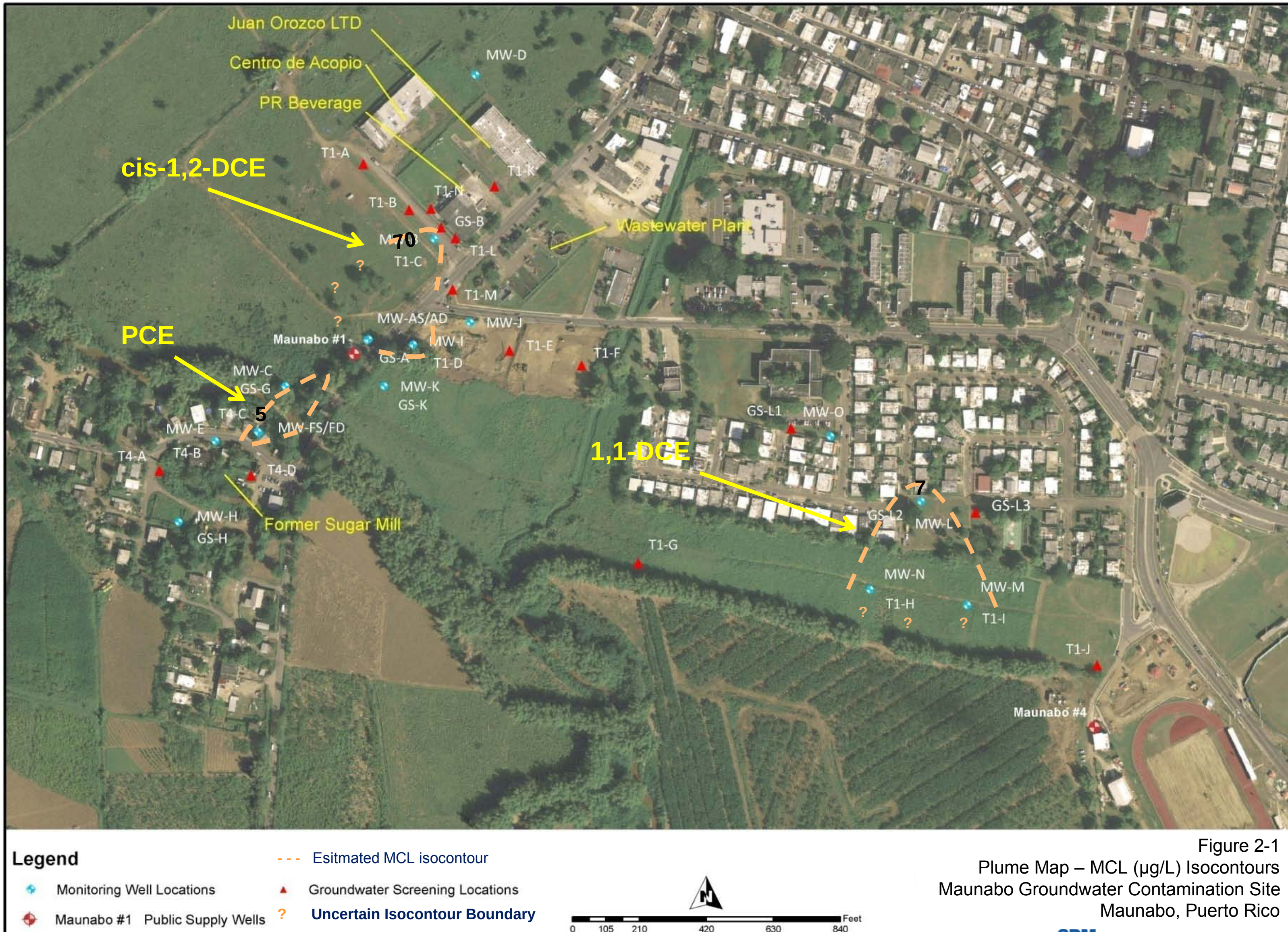
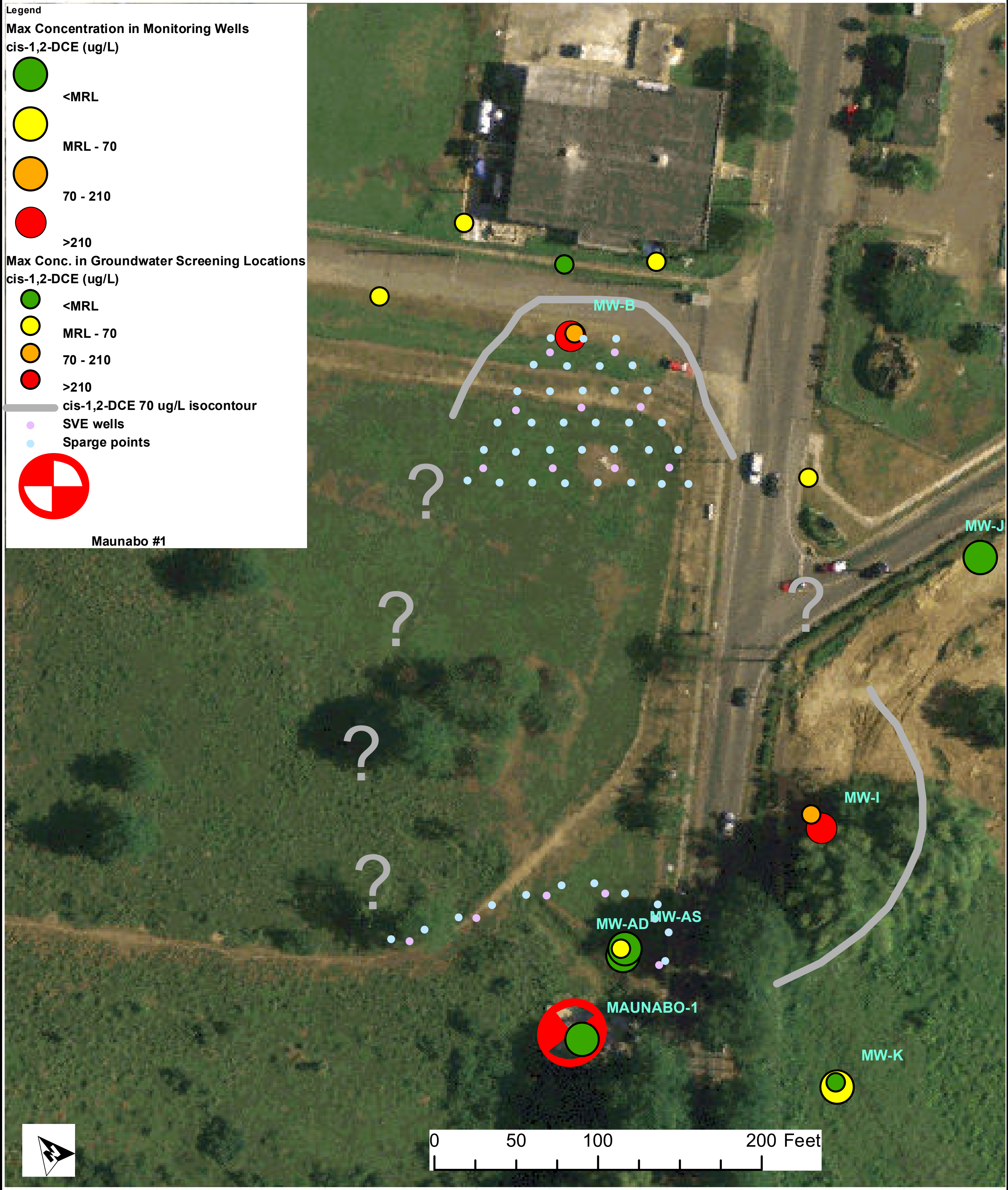


Figure 2-1
Plume Map – MCL (µg/L) Isocontours
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

R2-0002475

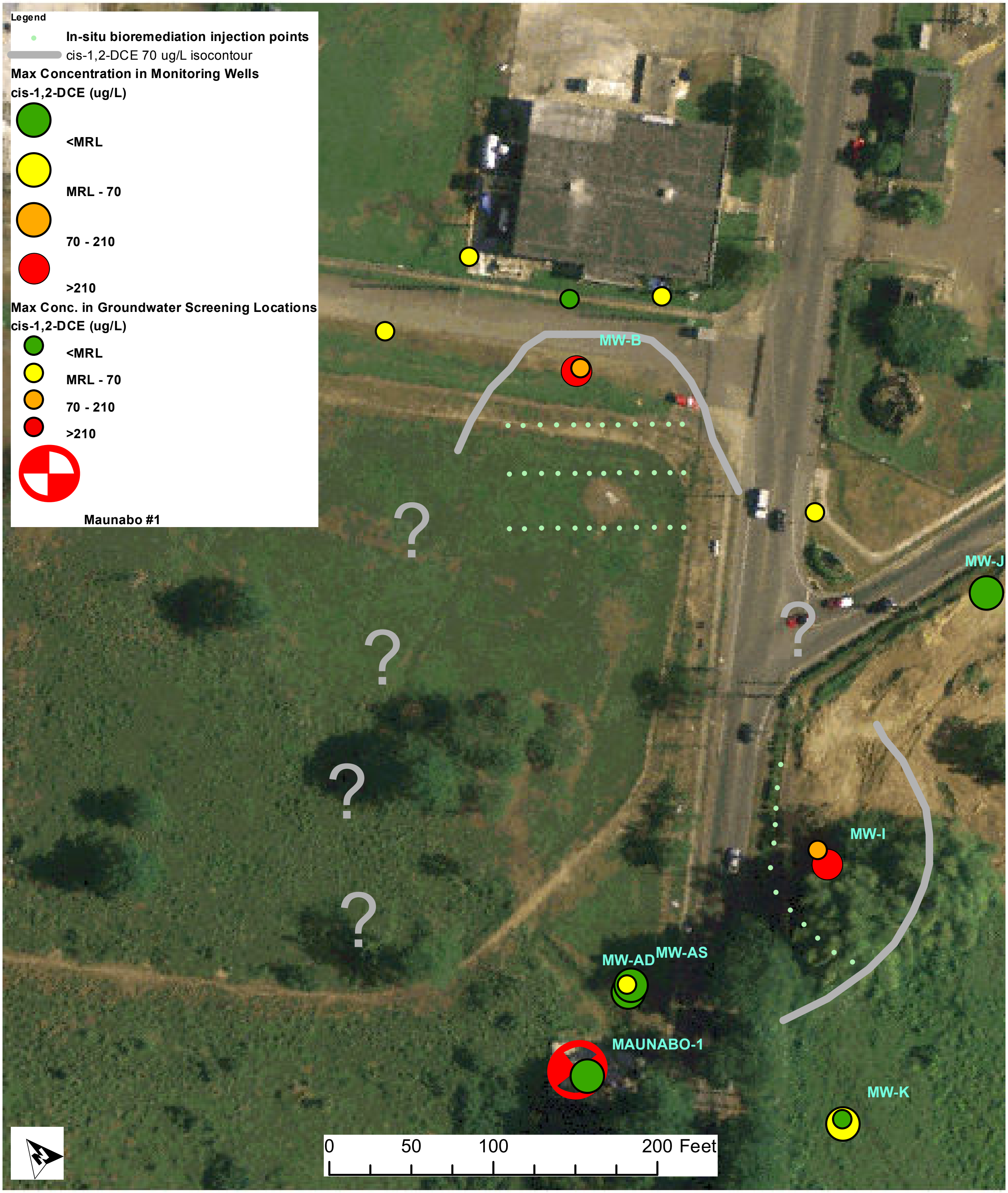


? = isocontour location is unknown
MRL = analytical method reporting limit

Figure 3-1
Conceptual Design of AS/SVE System in cis-1,2-DCE Plume
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

CDM Smith

R2-0002476



? = isocontour location is unknown
MRL = analytical method reporting limit

Figure 3-2
Conceptual Design of In-situ Bioremediation in cis-1,2-DCE Plume
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

R2-0002477

Appendix A

Cost Estimate Backup

Alternative 2
Monitored Natural Attenuation (all 3 plumes)
Cost Estimate Summary
Maunabo Groundwater ContaminationSite
Maunabo, Puerto Rico

Item No.	Item Description	Extended Cost	
CAPITAL COSTS			
1.	Remedial Design - Modeling	$	137,440
2.	Remedial Action - Well Installation	$	205,000
	Contingency (20%)	$	27,488
	TOTAL CAPITAL COSTS	**$**	**369,928**
OPERATION & MAINTENANCE (O&M) COSTS			
Annual O&M Costs			
3a.	Quarterly Monitoring Cost for Years 1 and 2	$	103,000
3b.	Annual Long-term Monitoring Cost for Years 3 to 30	$	126,000
PRESENT WORTH OF 30 YEAR COSTS (with discounting)			
4.	Total Capital Costs	$	369,928
5.	Long-term Monitoring Cost	$	2,098,449
	TOTAL PRESENT WORTH OF 30 YEAR COSTS	**$**	**2,468,000**

Note:

1. Present worth calculation assumes 7% discount rate after inflation is considered

CDM Smith

CDM Federal Programs Corporation

Maunabo	COMPUTED BY : CG	CHECKED BY: CFT
	DATE : 4/27/2012	DATE CHECKED: 4/27/2012
USEPA		

Description: Individual Cost Item Backup for Alternative 2

		Quantity	Unit	Unit Cost		Extended Cost
No. 1	**Modeling**					
1a.	**Modeling Work Plan**					
	Project Manager	4	hr	$160	=	$640
	Project Engineer	20	hr	$110	=	$2,200
	Geologist	20	hr	$110	=	$2,200
	Groundwater modeler	80	hr	$110	=	$8,800
	Total Work Plan Development					$13,840
1b.	**Groundwater modeling**					
	Includes groundwater modeling and report writing					
	Project Manager	40	hr	$160	=	$6,400
	Project Engineer	100	hr	$110	=	$11,000
	Geologist	100	hr	$110	=	$11,000
	Groundwater modeler	400	hr	$110	=	$44,000
	Total groundwater modeling					$72,400
1c	Project management and meeting	320	hr	$160.00	=	$51,200
	TOTAL REMEDIAL DESIGN					**$137,440**

CDM Smith
CDM Federal Programs Corporation

Maunabo	COMPUTED BY :	CG	CHECKED BY:	CFT
	DATE :	4/27/2012	DATE CHECKED:	4/27/2012
USEPA				

Description: Individual Cost Item Backup for Alternative 2

		Quantity	Unit	Unit Cost		Extended Cost
No. 2	**Well Installation**					
2a.	**Project Management, Office Support**					
	Include project management, subcontractor procurement, preparation of QAPP and SHSP					
	Project Manager	4	hr	$160	=	$640
	Project Engineer	40	hr	$110	=	$4,400
	Geologist	40	hr	$110	=	$4,400
	Procurement Specialist	40	hr	$110	=	$4,400
	Total Project Management and Office Support					$13,840
2b.	**Well Installation**					
	Monitoring Wells to install	10	wells			
	Well depth	100	ft			
	Screen length	10	ft			
	Drilling					
	Driller mob/demob	1	LS	$15,000	=	$15,000
	Boring 10-inch Hollow stem auger	1,000	ft	$58	=	$58,000
	4-inch PVC screen	100	ft	$26	=	$2,600
	4-inch PVC casing	900	ft	$16	=	$14,400
	Well completion materials	900	ft	$20	=	$18,000
	Well development	16	hr	$170	=	$2,720
	Drums	4	LS	$120	=	$480
	Drum transport	4	LS	$160	=	$640
	Stick up	2	LS	$550	=	$1,100
	Field Geologist					
	Mob/demob	30	hr	$110	=	$3,300
	Well drilling and development	70	hr	$110	=	$7,700
	Travel Expense and per Diem					
	Van and car rental	7	day	$95	=	$665
	Per diem	7	day	$162	=	$1,131
	Misc	7	day	$75	=	$525
	IDW Disposal					
	Disposal	1	LS	$26,000	=	$26,000
	Subtotal for Monitoring Wells installation					$152,261
2c.	Project management and meeting	240	hr	$160	=	$38,400
	TOTAL PRE-DESIGN INVESTIGATION:					**$205,000**

CDM Smith

CDM Federal Programs Corporation

PROJECT: Maunabo	COMPUTED BY: CG	CHECKED BY: CFT
JOB NO.:	DATE: 4/27/2012	DATE CHECKED: 4/27/2012
CLIENT: USEPA		

Description: Individual Cost Item Backup for Alternative 2

		Quantity	Unit	Unit Cost		Extended Cost
No. 3	**Long-term monitoring and Monitored Natural Attenuation**					
	Monitoring Wells to sample	26	wells			
	Number of samplers	2	people			
	Number of 12 hour workdays	7	days			
	Sampling Project Planning (e.g., Staffing, Lab Procurement, Obtaining Equipment)					
	Project Manager	16	hr	$160	=	$2,560
	Scientist	50	hr	$110	=	$5,500
	Procurement Specialist	40	hr	$110	=	$4,400
	Field Sampling Labor					
	Mob/demob	60	hr	$95	=	$5,700
	Well Sampling	168	hr	$85	=	$14,280
	Travel Expense and per Diem					
	Van and car rental	7	day	$95	=	$665
	Per diem	7	day	$323	=	$2,261
	Sampling Equipment, Shipping, Consumable Supplies					
	Equipment & PPE	1	ea	$3,500	=	$3,500
	Shipping	7	day	$500	=	$3,500
	Misc	7	day	$75	=	$525
	Sampling Analysis					
	VOCs	33	ea	$120	=	$3,960
	MEE	33	ea	$120	=	$3,960
	TOC	33	ea	$40	=	$1,320
	Nitrate	33	ea	$18	=	$594
	Sulfate	33	ea	$18	=	$594
	Ferrous Iron	33	ea	$18	=	$594
	Chloride	33	ea	$15	=	$495
	Alkalinity	33	ea	$20	=	$660
	Metals	33	ea	$120	=	$3,960
	Dehalococcoides	26	ea	$450	=	$11,700
	Data Validation					
	Assume samples validated @ 0.5 hrs per sample					
	Samples management/validation	162	hr	$150	=	$24,225
	Sampling Report					
	Project Manager	30	hr	$160	=	$4,800
	Environmental Engineer	100	hr	$110	=	$11,000
	Scientist	100	hr	$110	=	$11,000
	Admin Clerk	50	hr	$75	=	$3,750
3a.	**QUARTERLY SAMPLING COST**					**$ 103,000**
3b.	**TOTAL ANNUAL GROUNDWATER SAMPLING COST**					**$ 126,000**

CDM Smith

CDM Federal Programs Corporation

PROJECT: Maunabo
JOB NO.:
CLIENT:

COMPUTED BY : CG
DATE : 4/27/2012

CHECKED BY: CFT
DATE CHECKED: 4/27/2012

Description: Individual Cost Item Backup for Alternative 2

PRESENT WORTH CALCULATIONS

Assume discount rate is 7%:

This is a recurring cost every year for n years.

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth

A= Annual amount

i = interest rate

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

a. **Total Quarterly Monitoring Costs - Years 1 and 2**

This cost occurs every quarter for the first 2 years

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

n =	8
quarterly rate i =	1.75%
The multiplier for $(P/A)_1$ =	**7.405**

b. **Total Annual Monitoring Costs - year 3 - 30**

Multiplier is (P/A) for thirty years minus (P/A) for years 1 and 2)

n =	30
i =	7%
The multiplier for $(P/A)_2$ =	**12.409**
n =	2
i =	7%
The multiplier for $(P/A)_2$ =	**1.808**
Net	**10.601**

Alternative 3
Air Sparging/Soil Vapor Extraction (cis-1,2-DCE) and MNA (PCE and 1,1-DCE)
Cost Estimate Summary
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Item No.	Item Description	Extended Cost	
CAPITAL COSTS			
1.	Pre-design Investigation	$	486,000
2.	Remedial Design	$	506,120
3.	AS/SVE	$	927,000
	Subtotal	**$**	**1,919,000**
	Contingency (20%)	$	185,400
	TOTAL CAPITAL COSTS	**$**	**2,104,400**
OPERATION & MAINTENANCE (O&M) COSTS			
Annual O&M Costs			
4.	Operations and Maintenance - sparge grid (1 year)	$	268,734
5.	Operations and Maintenance - sparge curtain (5 years)	$	79,300
6a.	Long-term Monitoring (Quarterly year 1 and 2)	$	103,000
6b.	Long-term Monitoring (Annually year 3 - 30)	$	126,000
PRESENT WORTH OF 30 YEAR COSTS (with discounting)			
7.	Total Capital Costs	$	2,104,400
8.	Operations and Maintenance	$	593,880
9.	Long-term Monitoring Cost (for 30 years)	$	2,098,449
	TOTAL PRESENT WORTH OF 30 YEAR COSTS	**$**	**4,797,000**

Note:

1. Present worth calculation assumes 7% discount rate after inflation is considered

2. Refer to Alternative 2 for individual cost backup for MNA and long-term monitoring.

CDM Smith

CDM Federal Programs Corporation

PROJECT: Maunabo	COMPUTED BY : CG	CHECKED BY: CFT
JOB NO.:	DATE : 4/27/2012	DATE CHECKED: 4/27/2012
CLIENT: USEPA		

Description: Individual Cost Item Backup for Alternative 3

		Quantity	Unit	Unit Cost		Extended Cost
No. 1	**Pre-design Investigation**					
1a.	**Project Management and Office Support**					
	Include project management, subcontractor procurement, preparation of QAPP and SHSP					
	Project Manager	20	hr	$160	=	$3,200
	Project Engineer	80	hr	$110	=	$8,800
	Geologist	80	hr	$110	=	$8,800
	Chemist	40	hr	$100	=	$4,000
	Procurement Specialist	40	hr	$110	=	$4,400
	Total Project Management and Office Support					$29,200
1b.	**Groundwater Screening**					
	Number of Locations	40	locations			
	Samples per location	4	samples			
	End depth at each location	45	ft			
	Drilling					
	Driller mob/demob	1	LS	$8,000	=	$8,000
	Direct push drilling	1,800	ft	$20	=	$36,000
	Groundwater Screening samples	160	ea	$100		$16,000
	Decon pad	1	LS	$1,000	=	$1,000
	Decon of equipment	40	hr	$100	=	$4,000
	Drum	10	ea	$120	=	$1,200
	Drum disposal/sampling	10	ea	$200	=	$2,000
	Field Sampling Labor					
	Persons	2	persons			
	12-hour days	20	days			
	Mob/demob	60	hr	$95	=	$5,700
	Sampling	480	hr	$95	=	$45,600
	Travel Expense and per Diem					
	Van and car rental	40	day	$95	=	$3,800
	Per diem	40	day	$118	=	$4,720
	Sampling Equipment, Shipping, Consumable Supplies					
	Equipment & PPE	1	ea	$4,000	=	$4,000
	Shipping	20	day	$500	=	$10,000
	Misc	20	day	$200	=	$4,000
	Sample Analysis					
	VOCs	188	ea	$120	=	$22,560
	Data Validation					
	Assume samples validated @ 0.5 hr per sample					
	Samples management/validation	94	hr	$120	=	$11,280
	Total Groundwater Screening					$179,860

CDM Smith	PROJECT: Maunabo	COMPUTED BY: CG	CHECKED BY: CFT
CDM Federal Programs Corporation	JOB NO.:	DATE: 4/27/2012	DATE CHECKED: 4/27/2012
	CLIENT: USEPA		

Description: Individual Cost Item Backup for Alternative 3

1c.	**Well Installation**					
	Monitoring Wells to install	10	wells			
	Well depth	100	ft			
	Screen length	10	ft			
	Drilling					
	Driller mob/demob	1	LS	$15,000	=	$15,000
	Boring 10-inch Hollow stem auger	1,000	ft	$58	=	$58,000
	4-inch PVC screen	100	ft	$26	=	$2,600
	4-inch PVC casing	900	ft	$16	=	$14,400
	Well completion materials	900	ft	$20	=	$18,000
	Well development	16	hr	$170	=	$2,720
	Drums	4	LS	$120	=	$480
	Drum transport	4	LS	$160	=	$640
	Stick up	2	LS	$550	=	$1,100
	Field Geologist					
	Mob/demob	30	hr	$110	=	$3,300
	Well drilling and development	70	hr	$110	=	$7,700
	Travel Expense and per Diem					
	Van and car rental	3	day	$95	=	$285
	Per diem	3	day	$118	=	$354
	Misc	3	day	$75	=	$225
	IDW Disposal					
	Disposal	1	LS	$26,000	=	$26,000
	Subtotal for Monitoring Wells installation					$150,804
1d.	**Synoptic Water Level and Groundwater Sampling**					
	Monitoring Wells to sample	26	wells			
	Number of samplers	2	people			
	Number of 12 hour workdays	7	days			
	Field Sampling Labor					
	Mob/demob	60	hr	$95	=	$5,700
	Well Sampling	168	hr	$95	=	$15,960
	Travel Expense and per Diem					
	Van and car rental	7	day	$95	=	$665
	Per diem	7	day	$118	=	$826
	Sampling Equipment, Shipping, Consumable Supplies					
	Equipment & PPE	1	ea	$3,500	=	$3,500
	Shipping	7	day	$1,000	=	$7,000
	Misc	7	day	$75	=	$525
	Sampling Analysis					
	VOCs	33	ea	$120	=	$3,960
	MEE	33	ea	$120	=	$3,960
	TOC	33	ea	$40	=	$1,320
	Nitrate	33	ea	$18	=	$594
	Sulfate	33	ea	$18	=	$594
	Ferrous Iron	33	ea	$18	=	$594
	Chloride	33	ea	$15	=	$495
	Alkalinity	33	ea	$20	=	$660
	Metals	33	ea	$120	=	$3,960
	Dehalococcoides	20	ea	$450	=	$9,000
	Data Validation					
	Assume samples validated @ 0.5 hr per sample					
	Samples management/validation	159	hr	$150	=	$23,775
	Total Synoptic Water Level and Groundwater Sampling					$83,088
1e.	**Pre-design Investigation Report**					
	Assume include the data evaluation and management during sampling					
	Project Manager/Senior Reviews	40	hr	$160	=	$6,400
	Project Engineer	120	hr	$110	=	$13,200
	Project Geologist	120	hr	$110	=	$13,200
	Chemist	50	hr	$100	=	$5,000
	Data Management	50	hr	$85	=	$4,250
	Total Pre-design Investigation Report					$42,050
	TOTAL PRE-DESIGN INVESTIGATION:					**$486,000**

CDM Smith
CDM Federal Programs Corporation

PROJECT: Maunabo	COMPUTED BY : CG	CHECKED BY: CFT
JOB NO.:	DATE : 4/27/2012	DATE CHECKED: 4/27/2012
CLIENT: USEPA		

Description: Individual Cost Item Backup for Alternative 3

		Quantity	Unit	Unit Cost			Extended Cost
No. 2	**Remedial Design**						
	To include the analysis of investigation results and existing data, preparation of the remedial design including draft, pre-final, and final design packages consisting of specifications, drawings, design analysis report, and construction cost estimate.						
	Prices are estimated based on CDM Smith's experience on similar projects; hourly rate is for design engineer						
	Project management and meetings	450	hr	$110	=		$49,500
	Site visits	1	LS	$10,000	=		$10,000
	Prepare for draft submittal	800	hr	$110	=		$88,000
	Cost estimate	80	hr	$110	=		$8,800
	Value engineering	120	hr	$110	=		$13,200
	Prepare for final submittal	800	hr	$110	=		$88,000
	Prepare for final cost estimate	80	hr	$110	=		$8,800
	Post final engineering support	200	hr	$110	=		$22,000
2b.	**Pilot Test**						
	Include project management, plans and reports, subcontractor procurement, operations						
	Project Manager	40	hr	$160	=	$	6,400
	Project Engineer	150	hr	$110	=	$	16,500
	Procurement Specialist	50	hr	$110	=	$	5,500
	Pilot sparge point installation						
	Number of sparge points	4	points				
	Installed depth	45	ft				
	Mob/demob	1	LS	$8,000	=	$	8,000
	Air sparge point installation	180	ft	$70	=	$	12,600
	Vault	4	each	$500	=	$	2,000
	Development	4	hr	$170	=	$	680
	Operations - 1 week pilot test						
	Technician	60	hr	$85	=	$	5,100
	Engineer	60	hr	$110	=	$	6,600
	Equipment and Supplies	1	LS	$500	=	$	500
	per diem and truck rental	5	d	$400		$	2,000
	Pilot system rental	1	ea	$12,000	=	$	12,000
	Sampling	10	ea	$250	=	$	2,500
						$	80,380
2c.	Modeling (Same as Alternative 2)					$	137,440
	TOTAL REMEDIAL DESIGN COST:						**$506,120**

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CDM Smith

CDM Federal Programs Corporation

PROJECT: Maunabo	COMPUTED BY: CG	CHECKED BY: CFT	
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CLIENT: USEPA			

Description: Individual Cost Item Backup for Alternative 3

		Quantity	Unit	Unit Cost			Extended Cost
No. 3	**AS/SVE System**						
3a.	**Construction Management - General Conditions**						
	Assume the construction would last 4 weeks						
	Pre-Mobilization Work Plans						
	Project Manager	120	hr	$160	=		$19,200
	Environmental Engineer	160	hr	$110	=		$17,600
	Scientist	160	hr	$110	=		$17,600
	Admin Clerk	80	hr	$75	=		$6,000
	Permit Applications						
	Project Manager	30	hr	$160	=		$4,800
	Environmental Engineer	100	hr	$110	=		$11,000
	Scientist	30	hr	$110	=		$3,300
	Subcontractor Procurement						
	Assume procurement of driller, IDW, laboratory, subcontractors						
	Project Manager	60	hr	$160	=		$9,600
	Environmental Engineer	300	hr	$110	=		$33,000
	Geologist	150	hr	$110			$16,500
	Scientist	150	hr	$110	=		$16,500
	Procurement specialist	500	hr	$110	=		$55,000
	During Construction						
	Project Manager (10 hrs/wk)	40	hr	$160	=		$6,400
	Engineer (16 hrs/wk)	64	hr	$110	=		$7,040
	Site Superintendent (20 hrs/wk)	80	hr	$110	=		$8,800
	Site Trucks (2 per work days)	1	month	$2,000	=		$2,000
	Per Diem (2 people per work days)	80	day	$118	=		$9,440
	Health and Safety Engineer (full time)	4	wk	$4,400	=		$17,600
	Admin Clerk (assume 4 hrs/wk)	16	hr	$75	=		$1,200
	Subcontract management (10 hrs/week)	40	hr	$85	=		$3,400
	Meetings	20	LS	$4,000	=		$80,000
	Construction weekly meeting	4	LS	$2,000	=		$8,000
	Two Trailers with utilities	2	mo	$2,000	=		$4,000
	Site Security						
	Assume full time security guard, 12 hours during the weekday and 24 hours per day on weekend						
	Security guard	4	wk	$4,320	=		$17,280
	Remedial Action Reports						
	Project Manager	40	hr	$160	=		$6,400
	Environmental Engineer	240	hr	$110	=		$26,400
	Scientist	80	hr	$110	=		$8,800
	Admin Clerk	40	hr	$75	=		$3,000
	Geologist	120	hr	$110	=		$13,200
	Total for Construction Management						$433,060
3b.	**Air sparge well installation**						
	Assume radius of influence = 10 feet						
	Number of sparge points	44	points				
	Installed depth	45	ft				
	Air sparge point installation	1980	ft	$70	=	$	138,600
	Vault	44	each	$500	=	$	22,000
	Development	44	hr	$170	=	$	7,480
	Trenching	500	ft	$11		$	5,500
						$	173,580
3c.	**Soil Vapor Extraction Well Installation**						
	Assume radius of influence = 20 feet						
	Number of SVE wells	15	wells				
	Depth	7	ft				
	Extraction well installation	105	ft	$95	=	$	9,975
	Well vault	15	ea	$500	=	$	7,500
	Plastic ground cover to prevent short circuiting	10000	sf	$1	=	$	10,000
	Trenching	500	ft	$11		$	5,500
						$	27,475

CDM Smith	PROJECT:	Maunabo	COMPUTED BY :	CG	CHECKED BY:	CFT
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3d.	**System Components**						
	Engineer's estimate based on experience w/ recent costs						
	Blower	1	ea	$2,000	=	$	2,000
	Compressor	1	ea	$12,000	=	$	12,000
	KO tank	1	ea	$2,300	=	$	2,300
	Control panel	1	ea	$5,000	=	$	5,000
	PLC/Autodialer	1	ea	$5,000	=	$	5,000
	Instrumentation		LS	$2,000	=	$	2,000
	Piping		LS	$2,000	=	$	2,000
	Wiring		LS	$5,000	=	$	5,000
	Solenoid valves	50	ea	$100	=	$	5,000
	Gauges	50	ea	$75	=	$	3,750
	Flowmeters	50	ea	$150	=	$	7,500
	Compressed air hose	3000	ft	$5	=	$	15,000
	Security Fencing	1100	ft	$30	=	$	33,000
	Gates	2	ea	$1,000		$	2,000
	Skid with mounting and housing		LS	$25,000	=	$	25,000
	Subtotal					$	126,550
3e.	**Hookup/Setup/Startup Testing**						
	For electrical, mechanical hookup, PLC programming, and testing						
	Electrical hookup	1	LS	$5,000	=	$	5,000
	2 electricians for 1 week	80	hrs	$100	=	$	8,000
	2 plumbers for 1 week	80	hrs	$90	=	$	7,200
	1 programmer for 1 week	40	hrs	$125	=	$	5,000
	2 engineers for 1 week	80	hrs	$120	=	$	9,600
	Miscellaneous		LS	$7,000	=	$	7,000
	Subtotal					$	41,800
	Subtotal						$882,845
	Insurance and bond (5%)						$44,142
	TOTAL						**$927,000**

CDM Smith

CDM Federal Programs Corporation

PROJECT: Maunabo	COMPUTED BY : CG	CHECKED BY: CFT
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Description: Individual Cost Item Backup for Alternative 3

		Quantity	Unit	Unit Cost			Extended Cost
No.4	**Annual O&M Labor and Reporting**						
	Assume 1 year of O&M for sparge points in upgradient area						
	Technician (8 hours per week)	52	wk	$720	=	$	37,440
	Engineer - Reporting (2 hours per	12	mo	$180	=	$	2,160
	Expenses	52	wk	$50	=	$	2,600
	Equipment and Supplies	52	wk	$25	=	$	1,300
	Electric costs	12	mo	$2,700	=	$	32,400
						$	75,900
4a.	**Performance Monitoring**						
	Groundwater and Vapor Stream Sampling						
	Assume 6 sampling events, baseline and five consecutive months						
	Field Sampling Labor						
	Assume 2 persons 2 days x 12 hour per day						
	Mob/demob						
	Project Manager	4	hr	$160	=	$	640
	Engineer	10	hr	$110	=	$	1,100
	Field Tech	40	hr	$85	=	$	3,400
	Sampling						
	1 Engineer	2	day	$1,320	=	$	2,640
	1 Field Tech	2	day	$1,100	=	$	2,200
	Per diem	4	day	$181	=	$	724
	Car rental	2	day	$95	=	$	190
	Equipment & PPE	1	LS	$3,000	=	$	3,000
	Shipping	2	day	$1,000	=	$	2,000
	Misc	2	day	$200	=	$	400
	Sampling Analysis						
	Vapor VOCs	1	ea	$250	=	$	250
	Aqueous VOCs	8	ea	$120	=	$	960
	MEE	8	ea	$120	=	$	960
	TOC	8	ea	$40	=	$	320
	Chloride	8	ea	$15	=	$	120
	Alkalinity	8	ea	$20	=	$	160
	Data Summary						
	Data validation	20.5	hr	$150	=	$	3,075
	Tabulate the data and prepare figures	1	LS	$3,000	=	$	3,000
	Prepare the data report	1	LS	$7,000	=	$	7,000
	Subtotal for Groundwater Sampling per event					$	32,139
	Subtotal for 6 Groundwater Sampling events					$	192,834
	TOTAL O&M COST						**$268,734**

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Description: Individual Cost Item Backup for Alternative 3

		Quantity	Unit	Unit Cost			Extended Cost
No.5	**O&M Labor and Reporting**						
	Assume 5 years of O&M for sparge curtain						
	Technician (8 hours per week)	52	wk	$720	=	$	37,440
	Engineer - Reporting (2 hours per month)	12	mo	$180	=	$	2,160
	Expenses	52	wk	$50	=	$	2,600
	Equipment and Supplies	52	wk	$25	=	$	1,300
	Electric costs	12	mo	$900	=	$	10,800
						$	54,300
	Reporting	1	per year	$25,000	=	$	25,000
	TOTAL ANNUAL O&M COST						**$79,300**

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Description: Individual Cost Item Backup for Alternative 3

6. The cost for LTM is the same as Alternative 2.

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CLIENT:	USEPA				

Description: Individual Cost Item Backup for Alternative 3

PRESENT WORTH CALCULATIONS

Assume discount rate is 7%:

This is a recurring cost every year for n years.

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth

A= Annual amount

i = interest rate

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

a. **Operations and Maintenance of Sparge Curtain**

The interest rate tables for i = 7% and n = 5 years

n = 5

i = 7%

The multiplier for $(P/A)_2$ = **4.100**

b. **Total Quarterly Monitoring Costs**

This cost occurs every quarter for the first 2 years

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

n = 8

quarterly rate i = 1.75%

The multiplier for $(P/A)_1$ = **7.405**

c. **Total Annual Monitoring Costs - year 3 - 30**

Multiplier is (P/A) for thirty years minus (P/A) for years 1 and 2)

n = 30

i = 7%

The multiplier for $(P/A)_2$ = **12.409**

n = 2

i = 7%

The multiplier for $(P/A)_2$ = **1.808**

Net **10.601**

Alternative 4
In-situ Bioremediation (cis-1,2-DCE) and
MNA (PCE and 1,1-DCE)
Cost Estimate Summary
Maunabo Groundwater Contamination Site
Maunabo, Puerto Rico

Item No.	Item Description		Extended Cost
CAPITAL COSTS			
1.	Pre-design Investigation	$	486,000
2.	Microcosm Study	$	60,000
3.	Pilot Study	$	400,000
4.	Remedial Design	$	425,740
5.	In Situ Bioremediation of cis-1,2-DCE plume	$	858,403
	Subtotal	**$**	**2,230,000**
	Contingency (20%)	$	171,681
	TOTAL CAPITAL COSTS	**$**	**2,401,681**
OPERATION & MAINTENANCE (O&M) COSTS			
Annual O&M Costs			
6a.	Long-term Monitoring (Quarterly years 1 and 2)	$	103,000
6b.	Long-term Monitoring (Annually years 3 to 30)	$	126,000
PRESENT WORTH OF 30 YEAR COSTS (with discounting)			
7.	Total Capital Costs	$	2,401,681
8.	Long-term Monitoring Cost (for 30 years)	**$**	**2,098,449**
	TOTAL PRESENT WORTH OF 30 YEAR COSTS	**$**	**4,500,000**

Notes:
1. Present worth calculation assumes 7% discount rate after inflation is considered.
2. Refer to Alternative 2 for MNA and long-term monitoring.

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CLIENT:	USEPA				

Description: Individual Cost Item Backup for Alternative 4

		Quantity	Unit	Unit Cost		Extended Cost
No. 1	**Pre-design Investigation**					
1a.	**Project Management and Office Support**					
	Include project management, subcontractor procurement, preparation of QAPP and SHSP					
	Project Manager	20	hr	$160	=	$3,200
	Project Engineer	80	hr	$110	=	$8,800
	Geologist	80	hr	$110	=	$8,800
	Chemist	40	hr	$100	=	$4,000
	Procurement Specialist	40	hr	$110	=	$4,400
	Total Project Management and Office Support					$29,200
1b.	**Groundwater Screening**					
	Number of Locations	40	locations			
	Samples per location	4	samples			
	End depth at each location	45	ft			
	Drilling					
	Driller mob/demob	1	LS	$8,000	=	$8,000
	Direct push drilling	1,800	ft	$20	=	$36,000
	Groundwater Screening samples	160	ea	$100		$16,000
	Decon pad	1	LS	$1,000	=	$1,000
	Decon of equipment	40	hr	$100	=	$4,000
	Drum	10	ea	$120	=	$1,200
	Drum disposal/sampling	10	ea	$200	=	$2,000
	Field Sampling Labor					
	Persons	2	persons			
	12-hour days	20	days			
	Mob/demob	60	hr	$95	=	$5,700
	Sampling	480	hr	$95	=	$45,600
	Travel Expense and per Diem					
	Van and car rental	40	day	$95	=	$3,800
	Per diem	40	day	$118	=	$4,720
	Sampling Equipment, Shipping, Consumable Supplies					
	Equipment & PPE	1	ea	$4,000	=	$4,000
	Shipping	20	day	$500	=	$10,000
	Misc	20	day	$200	=	$4,000
	Sample Analysis					
	VOCs	188	ea	$120	=	$22,560
	Data Validation					
	Assume samples validated @ 0.5 hr per sample					
	Samples management/validation	94	hr	$120	=	$11,280
	Total Groundwater Screening					$179,860
1c.	**Well Installation**					
	Monitoring Wells to install	10	wells			
	Well depth	100	ft			
	Screen length	10	ft			
	Drilling					
	Driller mob/demob	1	LS	$15,000	=	$15,000
	Boring 10-inch Hollow stem auger	1,000	ft	$58	=	$58,000
	4-inch PVC screen	100	ft	$26	=	$2,600
	4-inch PVC casing	900	ft	$16	=	$14,400
	Well completion materials	900	ft	$20	=	$18,000
	Well development	16	hr	$170	=	$2,720
	Drums	4	LS	$120	=	$480
	Drum transport	4	LS	$160	=	$640
	Stick up	2	LS	$550	=	$1,100
	Field Geologist					
	Mob/demob	30	hr	$110	=	$3,300
	Well drilling and development	70	hr	$110	=	$7,700
	Travel Expense and per Diem					
	Van and car rental	3	day	$95	=	$285
	Per diem	3	day	$118	=	$354
	Misc	3	day	$75	=	$225
	IDW Disposal					
	Disposal	1	LS	$26,000	=	$26,000
	Subtotal for Monitoring Wells installation					$150,804

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1d.	**Synoptic Water Level and Groundwater Sampling**					
	Monitoring Wells to sample	26	wells			
	Number of samplers	2	people			
	Number of 12 hour workdays	7	days			
	Field Sampling Labor					
	Mob/demob	60	hr	$95	=	$5,700
	Well Sampling	168	hr	$95	=	$15,960
	Travel Expense and per Diem					
	Van and car rental	7	day	$95	=	$665
	Per diem	7	day	$118	=	$826
	Sampling Equipment, Shipping, Consumable Supplies					
	Equipment & PPE	1	ea	$3,500	=	$3,500
	Shipping	7	day	$1,000	=	$7,000
	Misc	7	day	$75	=	$525
	Sampling Analysis					
	VOCs	33	ea	$120	=	$3,960
	MEE	33	ea	$120	=	$3,960
	TOC	33	ea	$40	=	$1,320
	Nitrate	33	ea	$18	=	$594
	Sulfate	33	ea	$18	=	$594
	Ferrous Iron	33	ea	$18	=	$594
	Chloride	33	ea	$15	=	$495
	Alkalinity	33	ea	$20	=	$660
	Metals	33	ea	$120	=	$3,960
	Dehalococcoides	20	ea	$450	=	$9,000
	Data Validation					
	Assume samples validated @ 0.5 hr per sample					
	Samples management/validation	159	hr	$150	=	$23,775
	Total Synoptic Water Level and Groundwater Sampling					$83,088
1e.	**Pre-design Investigation Report**					
	Assume include the data evaluation and management during sampling					
	Project Manager/Senior Reviews	40	hr	$160	=	$6,400
	Project Engineer	120	hr	$110	=	$13,200
	Project Geologist	120	hr	$110	=	$13,200
	Chemist	50	hr	$100	=	$5,000
	Data Management	50	hr	$85	=	$4,250
	Total Pre-design Investigation Report					$42,050
	TOTAL PRE-DESIGN INVESTIGATION:					**$486,000**

CDM Smith

CDM Federal Programs Corporation

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CLIENT:	USEPA				

Description: Individual Cost Item Backup for Alternative 4

		Quantity	Unit	Unit Cost		Extended Cost
No. 4	**Remedial Design**					
	To include the analysis of investigation results and existing data, preparation of the remedial design including draft, pre-final, and final design packages consisting of specifications, drawings, design analysis report, and construction cost estimate.					
	Prices are estimated based on CDM Smith's experience on similar projects; hourly rate is for design engineer					
	Project management and meetings	450	hr	$110	=	$49,500
	Site visits	1	LS	$10,000	=	$10,000
	Prepare for draft submittal	800	hr	$110	=	$88,000
	Cost estimate	80	hr	$110	=	$8,800
	Value engineering	120	hr	$110	=	$13,200
	Prepare for final submittal	800	hr	$110	=	$88,000
	Prepare for final cost estimate	80	hr	$110	=	$8,800
	Post final engineering support	200	hr	$110	=	$22,000
	Modeling (Same as Alternative 2)					$137,440
	TOTAL REMEDIAL DESIGN COST:					**$425,740**

CDM Smith

CDM Federal Programs Corporation

PROJECT:	Maunabo	COMPUTED BY :	YS
JOB NO.:		DATE :	4/27/2012
CLIENT:	USEPA	CHECKED BY:	CFT
		DATE CHECKED:	4/27/2012

Description: Individual Cost Item Backup for Alternative 4

		Quantity	Unit	Unit Cost		Extended Cost
No. 5	**In-situ Bioremediation in cis-1,2-DCE plume**					
5a.	**Construction Management - General Conditions**					
	Assume the construction would last 4 weeks					
	Pre-Mobilization Work Plans					
	Project Manager	120	hr	$160	=	$19,200
	Environmental Engineer	160	hr	$110	=	$17,600
	Scientist	160	hr	$110	=	$17,600
	Admin Clerk	80	hr	$75	=	$6,000
	Permit Applications					
	Project Manager	30	hr	$160	=	$4,800
	Environmental Engineer	100	hr	$110	=	$11,000
	Scientist	30	hr	$110	=	$3,300
	Subcontractor Procurement					
	Assume procurement of driller, IDW, laboratory, injection subcontractors					
	Project Manager	60	hr	$160	=	$9,600
	Environmental Engineer	40	hr	$110	=	$4,400
	Geologist	30	hr	$110		$3,300
	Scientist	30	hr	$110	=	$3,300
	Procurement specialist	50	hr	$110	=	$5,500
	During Construction					
	Project Manager (10 hrs/wk)	40	hr	$160	=	$6,400
	Engineer (16 hrs/wk)	64	hr	$110	=	$7,040
	Site Superintendent (10 hrs/wk)	40	hr	$110	=	$4,400
	Site Trucks (2 per work days)	1	month	$2,000	=	$2,000
	Per Diem (2 people per work days)	19	day	$323	=	$6,202
	Health and Safety Engineer (16 hrs/wk)	64	hr	$110	=	$7,040
	Admin Clerk (assume 4 hrs/wk)	16	hr	$75	=	$1,200
	Subcontract management (10 hrs/week)	40	hr	$85	=	$3,400
	Meetings	3	LS	$4,000	=	$12,000
	Construction weekly calls	10	per	$500	=	$5,000
	Two Trailers with utilities	1	LS	$10,000	=	$10,000
	Site Security					
	Assume full time security guard, 12 hours during the weekday and 24 hours per day on weekend					
	Security guard	4	wk	$4,320	=	$17,280
	Remedial Action Reports					
	Project Manager	40	hr	$160	=	$6,400
	Environmental Engineer	240	hr	$110	=	$26,400
	Scientist	80	hr	$110	=	$8,800
	Admin Clerk	40	hr	$75	=	$3,000
	Geologist	120	hr	$110	=	$13,200
	Total for Construction Management					$245,362

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5b.	**Amendment - EHC Installation**					
	Assume using bio-barrier type application					
	Length of treatment zone	120	ft			
	Width of treatment zone	10	ft			
	Treatment zone thickness	15	ft			
	Treatment zone volume	18,000	ft^3			
	Assume soil bulk density	100	lb/ft^3			
	Mass of soil in treatment zone	1,800,000	lbs			
	Estimated total porosity	0.2				
	Volume pore space	3,600	ft^3			
	EHC mass calculations:					
	Percentage EHC by soil mass	0.15%	lb EHC/lb soil			
	Total Mass of EHC required	2,700	lbs EHC per row			
	Total Mass of EHC required	10,800	lbs EHC 4 rows			
	Injection details:					
	Radius of influence	5	ft			
	Assume 4 bio-barrier type applications, each is	120	ft long			
	Number of injection points	48				
	Mass of EHC per point	225	lbs			
	EHC concentration in groundwater	0.75	lbs/ft^3			
	Assume percent solids in slurry	25%				
	Mass of slurry	10,800	lbs			
	Slurry volume to inject in one bio-barrier	1,295	gal			
	Total Slurry volume to inject	5,180	gal			
	Total Amendment Quantity and Cost	2,700	lbs	$1.90	=	$5,130
	Injection Operation					
	Assume using direct push injection					
	Assume injections installed using 1 drill rig, in 1 day	5	points			
	Mob/demob	1	LS	$3,500	=	$3,500
	Total days of injection	10	day			
	Drilling and injection cost	10	ea	$5,000	=	$48,000
	Subtotal of injection operation at overburden					$51,500
	Total for Amendment - EHC installation					$56,630
5c.	**Bioaugmentation**					
	Assume bioaugmenation will initially be conducted at 3 areas: MW-B, MW-I, MW-K					
	Assume that bioaugmentation at other areas can be conducted by transferring groundwater from the augmented area to there					
	Total for Bioaugmentation	1	LS	$50,000	=	$50,000
5d.	**Performance Monitoring - Groundwater Sampling**					
	Groundwater Sampling					
	Assume 6 wells and 6 sampling events, i.e, baseline and once per year for five years					
	Field Sampling Labor					
	Assume 2 persons, 3 days x 12 hour per day					
	Mob/demob					
	Project Manager	8	hr	$160	=	$1,280
	Engineer	20	hr	$110	=	$2,200
	Field Tech	40	hr	$85	=	$3,400
	Sampling					
	1 Engineer	3	day	$880	=	$2,640
	2 Field Tech	3	day	$2,040	=	$6,120
	Per diem	6	day	$162	=	$969
	Car rental	6	day	$95	=	$570
	Equipment & PPE	1	LS	$3,000	=	$3,000
	Shipping	3	day	$1,000	=	$3,000
	Misc	3	day	$200	=	$600
	IDW Costs					
	IDW Disposal	1	LS	$1,800	=	$1,800
	Sampling Analysis					
	LDL VOCs	10	ea	$120	=	$1,200
	MEE	6	ea	$120	=	$720
	TOC	6	ea	$40	=	$240
	Nitrate	6	ea	$18	=	$108
	Sulfate	6	ea	$18	=	$108
	Chloride	6	ea	$15	=	$90
	Bromide	6	ea	$15	=	$90
	Alkalinity	6	ea	$20	=	$120
	Analysis for metals	6	ea	$150	=	$900
	Data Summary					
	Assume samples validated @ 0.5 hr per sample					
	Data validation	29	hr	$150	=	$4,350
	Tabulate the data and prepare figures	1	LS	$8,000	=	$8,000
	Prepare the data report	1	LS	$25,000	=	$25,000
	Subtotal for Groundwater Sampling per event					$66,505
	Subtotal for 6 Groundwater Sampling events					$399,030
	Total Performance Monitoring - Groundwater Sampling					$465,535
	Subtotal for In-situ Bioremediation					$817,527
	Insurance and bond (5%)					$40,876
	TOTAL IN-SITU BIOREMEDIATION					**$858,403**

CDM Smith	PROJECT:	Maunabo	COMPUTED BY :	YS	CHECKED BY: CFT
	JOB NO.:		DATE :	4/12/2012	DATE CHECKED: 4/27/2012
CDM Federal Programs Corporat	CLIENT:	USEPA			

Description: Individual Cost Item Backup for Alternative 4

PRESENT WORTH CALCULATIONS

Assume discount rate is 7%:

This is a recurring cost every year for n years.

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth

A= Annual amount

i = interest rate

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

8a. **Total Quarterly Monitoring Costs - Years 1 and 2**

This cost occurs every quarter for the first 2 years

$$P = A \times \frac{(1+i)^n - 1}{i(1+i)^n}$$

n = 8

quarterly rate i = 1.75%

The multiplier for $(P/A)_1$ = **7.405**

8b. **Total Annual Monitoring Costs - year 3 - 30**

Multiplier is (P/A) for thirty years minus (P/A) for years 1 and 2)

n = 30

i = 7%

The multiplier for $(P/A)_2$ = **12.409**

n = 2

i = 7%

The multiplier for $(P/A)_2$ = **1.808**

Net **10.601**

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